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STEERING SYSTEM SURVEY FOR SURFACE MINING EQUIPMENT

National Mine Health & Safety
Learning Resource Center
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Prepared for

UNITED STATES DEPARTMENT OF INTERIOR
BUREAU OF MINES

by

WOODWARD ASSOCIATES, INC.

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16. Abstract (Limit: 200 words) <p>The evolution of surface mining equipment has resulted in larger, faster haulage units, loaders, etc., resulting in increased demands on steering technology. Careful analysis of these systems was warranted to determine if steering-related safety problems have been introduced.</p> <p>The objectives of this program were to:</p> <ol style="list-style-type: none">1. Define the generic types of steering systems being used on mobile mining equipment used in surface mining operations.2. Gather information on steering-related accidents in mining operations.3. Assess the need for initiating government-sponsored research into steering system technology. <p>A comprehensive literature survey was conducted concurrent with extensive contacts with mining operations, mining equipment manufacturers, steering system component manufacturers, and government agencies. A Technical Evaluation Group composed of representatives from the above organizations was formed to review the data gathered.</p> <p>It was concluded that the steering systems in use on surface mining equipment are reliable and do not present a safety problem. The Society of Automotive Engineers, Inc. is active in preparing voluntary consensus standards to assure that the minimum levels of performance are defined for industry.</p>		13. Type of Report & Period Covered Program Final Report Sept. 1977 - Apr. 1979	
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FOREWORD

This report was prepared by Woodward Associates, Inc. under USBM Contract number JO275014. The contract was initiated under the Coal Program. It was administered under the technical direction of the Twin Cities Mining Research Center with Mr. Bruce Nelson acting as the Technical Project Officer. Mr. Ron Simonich was the contract administrator for the Bureau of Mines. This report is a summary of the work recently completed as part of this contract during the period September 21, 1977 to April 20, 1979. This report was submitted by the authors on April 20, 1979.

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EXECUTIVE SUMMARY

INTRODUCTION

The Bureau of Mines has an important role in assuring that this nation's miners are able to perform their duties in a workplace environment that is safe. As a sponsor of research leading toward the development and production of safer mining equipment, the Bureau of Mines aids the mining and equipment manufacturing industries in accelerating the design and demonstration phases of new mining equipment development. The Bureau of Mines also attempts to anticipate new safety problems that might develop as the mining industry uses larger and more complex machinery. Comprehensive surveys of areas of expanding technology are required to identify those areas where research funds might best be spent and where the Bureau's efforts might best be directed. The engineering data collected in such surveys provide the Bureau with the required decision criteria.

The expansion of mine production has required the development of larger and more productive loaders, scrapers, haulage trucks, and similar equipment. These machines have required the development and production of more powerful and complex steering systems. Steering system technology has advanced at a rapid pace. Upgrading of older system technology was not appropriate from engineering or economic viewpoints; the development of new system technology has resulted.

On September 21, 1977, Woodward Associates, Inc. (WAI) was awarded a contract by the Bureau of Mines to conduct a "Steering System Survey for Surface Mining Equipment" (USBM Contract No. J0275014). The objectives of this project were to define the specific types of steering systems now in use in

wheeled surface mining equipment, gather information on the mining accidents resulting from malfunctions of equipment steering systems, estimate the relative numbers and sizes of mobile mining equipment in use in coal and non-coal mining operations, and then to evaluate the need for new Bureau research projects or additional Mine Safety and Health Administration regulations.

PROJECT APPROACH

The project was organized as follows:

- Through a literature search and meetings with mine equipment manufacturers the steering system approaches being used in mining equipment were defined and described.
- Several sources of mine accident data were queried to gather representative information on mobile mining equipment accidents resulting from steering system failures.
- An estimate of the population of mobile mining equipment in use in U.S. mines was prepared using available Bureau of Mines information.

The material gathered during the three concurrent activities mentioned above was assembled into a report for review and discussion with a selected group of mine and equipment industry personnel. This group, hereafter referred to as the Technical Evaluation Group, was composed of representatives from the following industry sectors:

- Mining companies
- Equipment manufacturers
- Steering system component suppliers
- Mine safety regulatory agencies (U.S. and Canada)

- Bureau of Mines
- Private research organizations

The Technical Evaluation Group held two working sessions to discuss the implications of the material gathered by Woodward Associates, Inc., and to offer additional information related to steering system technology field operational experiences, regulatory approaches to steering safety, and on activities of standards-making groups. The enthusiastic activity of members of this group, both during the working sessions and in the independent efforts performed to gather data for the meetings, was significant in assuring that all aspects and implications of the many facets of the mine equipment steering system subject were addressed.

STEERING SYSTEM INFORMATION

A manual literature review included reports published by the Society of Automotive Engineers, Inc., publications of the National Safety Council, and equipment manufacturer's manuals and internal publications. Computer-aided literature searches were conducted using the National Technical Information System and the Engineering Index. This literature review/search resulted in identification of 57 open-literature publications that were useful in defining the types of steering systems in use. The literature available contained no documentation of steering system design deficiencies or indications of potential future steering safety problems. The reports obtained from the Society of Automotive Engineers, Inc. were by far the most useful.

Useful accident data were obtained through the Mine Safety and Health Administration's Health and Safety Analysis Center (MSHA-HSAC) in Denver, Colorado and from British Columbia's Department of Mines and Petroleum Resources. A portion of the MSHA-HSAC injury accident and fatal accident



records for 1976 and 1977 were examined for accidents that were directly caused by steering failures or in which the steering system contributed to the occurrence of the accident. Of the over 1000 mobile equipment accidents studied, only 13 had causative factors that may have been steering-related. Of these 13 accidents, only 5 are clearly related to steering systems; 2 of these 5 were caused by steering system malfunctions. In contrast to these low accident figures, mobile equipment rollovers and/or nonuse of seat belts resulted in 28 fatalities and 173 injuries in the same group of 1021 accidents; slips/falls and other ladder-related accidents accounted for 266 injuries.

The Department of Mines and Petroleum Resources, British Columbia, provided accident information that was especially interesting. These reports include accidents that did not happen to result in death or injury to the equipment operator as well as accidents that did result in injury or death. Of the 1016 incidents reviewed, 32 were either steering system failures or "loss of control." None of the steering system failures resulted in injury or death to the equipment operator. These data indicated that wheel spindle failure was a primary cause of steering system-related incidents.

Steering system malfunctions or failures appear to be an area for concern by mine maintenance personnel, however, these malfunctions and failures are not causing significant numbers of injuries and fatalities in mine accidents.

In recent years the manufacturers of mobile mining equipment have provided emergency (sometimes called auxiliary or supplementary) steering capability on machines that have speed capabilities over 10-15 miles per hour. The Society of Automotive Engineers, Inc. (SAE) has recently prepared a Recommended Practice that defines the desirable performance requirements for emergency steering systems on mining and

construction machines. The technical approach used in this standard is being considered by the International Organization for Standardization (ISO) and if adopted, would become a worldwide standard.

CONCLUSIONS

Consideration of the material on steering systems gathered during this study, coupled with the discussion and comments of the Technical Evaluation Group, has led Woodward Associates, Inc. to prepare the following conclusions:

1. Today's state-of-the-technology is producing reliable steering systems.
2. Advances in steering system reliability will not produce significant reductions in surface mine injury/fatality accidents.
3. Steering system technology advances could result in lowering of maintenance requirements and increased machine availability.
4. Proper equipment operator training and increased equipment operator discipline have the potential to reduce equipment accidents and improve mine productivity.
5. It is desirable to have emergency steering capability to accommodate the "engine-off" situation.
6. The accident records at the MSHA-HSAC offices and available from British Columbia are extremely useful for placing equipment safety research in perspective.

These conclusions lead to the development of several recommendations for Bureau of Mines' consideration and suggestions for actions by the Mine Safety and Health Administration.



RECOMMENDATIONS

The Bureau of Mines is sponsoring a broad range of equipment safety research. The following recommendations are influenced by a larger view than that of the steering system needs alone. It is Woodward Associates' recommendation that the Bureau initiate no additional safety research, studies, or demonstrations solely oriented toward mobile mining equipment steering systems. The efforts of the equipment manufacturers and the steering system component suppliers are completely satisfactory to assure continued technology advancement. There are areas of endeavor that could be enhanced by Bureau of Mines involvement. These areas are covered by the following recommendations:

1. Continue the development and demonstration of materials and techniques that can be used in the training of equipment operators. The training of equipment operators to handle emergency or abnormal events experienced during equipment operation is especially important. (The Bureau has projects under way in this area.)
2. Include steering system inspection procedures as an integral part of equipment operator training programs. (The Bureau is following this recommendation on some projects.)
3. Assist the Mine Safety and Health Administration personnel in becoming technically conversant on desirable steering system features such as emergency steering capability, and on the general approaches to proper steering system maintenance.

4. Conduct an evaluation of the potential positive and negative effects of requirements to use fire resistant fluids in the hydraulic systems of mobile mining equipment.

The above recommendations are generally oriented toward addressing the safety of the equipment operator. The following recommendations are generally oriented toward improving the productivity of mining operations and, therefore, may be considered by the Department of Energy as well as the Bureau of Mines:

5. Prepare a booklet presenting guidelines for the maintenance of hydraulic systems on mobile mining equipment.
6. Prepare a report describing the function, care, and maintenance of hydraulic system seals on mobile mining equipment. This document should cover installation procedures.

The following recommendations are directed to the Mine Safety and Health Administration:

1. Consider a general upgrading of the causal information contained in mine accident reports. Include representatives from equipment manufacturers as part of accident investigation team. Stress accurate identification of the machine involved. Stress identification of the primary and contributory causes of accidents.
2. Provide technical information for distribution by MSHA field personnel to the mines. Specifically, in the area of equipment steering systems, provide information on inspection

procedures, on emergency steering performance standards (SAE Recommended Practice J53), and on industry accident experience.

SECTION 1.0
INTRODUCTION

The past few decades have produced remarkable changes in the size and productivity of mobile surface mining machines. Front-end loaders have developed that have loading bucket capacities up to 36 cubic yards; several years ago a front-end loader with a bucket capacity of 5-6 cubic yards was considered to be large. The gross vehicle weights of the largest front-end loaders now approach 200 tons. The capacities of haulage trucks have progressed from the 22-50 ton range to production models with payloads of 250 tons. A prototype haulage truck with a payload of 350 tons has been in field evaluation in recent years. Motor graders have grown from gross vehicle weights of 15-25 tons to about 100 tons.

The large machines now in use in surface mining operations could present new safety problems. Has the technology of the control components been advanced to assure safe steering and braking? Do the safety devices and systems used on smaller machines provide adequate safety on these large machines? Are there operator visibility problems with these large machines? The U.S. Bureau of Mines, through this project and others, is attempting to provide answers to these questions and, where necessary, demonstrate solutions to new safety problems. This study project results from the need to identify the steering problems, if any, that have resulted from the increase in size of mobile surface mining machines. This study does not include tracked or crawler mounted machines; only rubber-tired surface mining machines (i.e., front-end loaders, haulage trucks, motor graders, scrapers, etc.) were studied. Should steering

technology deficiencies be discovered, specific recommendations for future U.S. Bureau of Mines research projects would be outlined for consideration. The potential benefits to the mining industry accrued through proposed U.S. Bureau of Mines research projects should also be quantified.

To provide the information from which to make judgments, to draw conclusions, and to prepare recommendations on steering systems, Woodward Associates, Inc. gathered technical data from the available literature and from component suppliers and machine manufacturers, gathered accident data from MSHA-HSAC and from British Columbia, and then reviewed this material with a group of qualified individuals from various parts of the mining industry. The following report presents the information gathered and the results of the analysis of this information.

Woodward Associates, Inc. is pleased to acknowledge the excellent cooperation of the companies manufacturing steering components and mining equipment. Special thanks go to the personnel at the Mine Safety and Health Administration's Health and Safety Analysis Center in Denver, Colorado for their continued cooperation and support. The contributions made by the many mining companies visited and by the United States and Canadian government agency personnel were extremely valuable.

SECTION 2.0

LITERATURE ON OFF-HIGHWAY EQUIPMENT STEERING SYSTEMS

As evidenced in the literature reviewed during this study, the development of efficient and reliable steering systems has been an important part of the evolution of off-highway equipment. The Society of Automotive Engineers, Inc. (SAE) has been, and continues to be, very active in the publication of technical reports covering the progress of technology in the mobile equipment area. Of the 57 technical reports gathered containing pertinent material to this study, 43 of these were published by SAE. Abstracts of all 57 reports are included in Table 1. In addition to these reports, WAI files containing equipment manufacturer service and maintenance manuals, operator's manuals, and equipment specifications were reviewed for pertinent steering system information. In instances where specific technical detail on the steering system of a particular machine model was desired, and the material was not in WAI files, the manufacturer was contacted directly.

This literature was very useful in describing the steering systems in use on, and being developed for, the off-highway machines used in surface mining operations. No reports were discovered that addressed steering safety problems on off-highway equipment.

Table 1. Abstracts of the Significant Literature

<u>TITLE</u>	<u>AUTHOR</u>	<u>AFFILIATION</u>	<u>SOURCE</u>	<u>DATE</u>
New Concepts in Hydraulic Controls for Mobile Equipment	W. T. Stephens H. N. Underwood	Borg-Warner Corp.	SAE 650669	1965
<p>Analyses and tests were made on various kinds of mobile equipment comparing open and closed center systems. The work cycle and maximum horsepower were kept equal in the comparison of these systems. The closed center system surpassed the open center in both cycle time and efficiency of operation.</p> <p>New concepts of the closed center system evolved from this work. These concepts included: controlled acceleration and deceleration, selective maximum volume control to prevent overspeeding, and a means of lowering the circuit pressure when the valves are in neutral.</p> <p>Gains with the integration of the hydrostatic transmission and the closed center hydraulic system are also demonstrated.</p>				
A New Era in Controllability - Hydrostatic Steering for Articulated Vehicles	B. C. Hudgens R. L. Goff	TRW, Inc.	SAE 660238	04-05-66
<p>With the advent of ever larger mobile machines in the earthmoving industry new methods of steering control had to be developed. Three basic systems which had sufficed in the past were mechanical, electrical, and hydraulic power steering mechanisms.</p> <p>This paper describes a new hydrostatic powersteering system which appears particularly applicable to large off-road construction machines. Basic features of the V2Hydraguide system are discussed. It is believed this system meets the general requirements for a high-flow steering unit and represents a new era in controllability for articulated vehicles.</p>				
Heavy Truck Steering System Analysis	T. J. Budzynski R. J. Parker	Ford Motor Company	SAE 660431	06-10-66
<p>This paper analyzes present-day heavy truck steering systems to provide a basis upon which to continue improvements. The discussion includes areas which mechanically and physiologically affect steering efforts and structural loads. Consideration is given to steering geometry, component design parameters, and human factors influential in the steering acceptability of a vehicle. This analysis is based on actual vehicle test data and a literature survey of related anthropometry.</p>				
System Approach - Hydraulic Power for Articulated Vehicles	T. J. Malott R. C. Westveer	N.Y. Air Brake Co. Hydreco Division	SAE 660614	09-12-66
<p>A new concept in construction equipment hydraulic systems has been developed that couples the implement and steering circuits in such a manner that constant steering horsepower is available throughout the engine speed range with no sacrifice in implement performance. This paper discusses the overall power requirements for articulated loaders and how this new system improves the overall efficiency.</p>				
A Pilot Experiment on Driver Task Performance with Fixed and Variable Steering Ratio	N. E. Shoemaker F. Dell'Amico R. J. Chwalek	Cornell Aeronautical University	SAE 670508	05-15-67

The experimental program described here was conducted in order to determine the effect of fixed and variable steering gear ratio on driver task performance. Three fixed gearbox ratios and two variable ratios of the Bendix Varamatic type were tested, using a single vehicle. Four steady turn driving tasks were used, each producing the same lateral "g" (0.2g) and a transient maneuver task, induced by applying a step change in front wheel angle to the vehicle, was also used. The pool of test subjects consisted of student drivers with an average of 39 hr of on-the-road driving experience.



Table 1. Abstracts of the Significant Literature (Cont)

<u>TITLE</u>	<u>AUTHOR</u>	<u>AFFILIATION</u>	<u>SOURCE</u>	<u>DATE</u>
Mechanical Controls for Vehicles with Hydrostatic Transmissions	R. D. Houk	North American Rockwell Corp.	SAE 690571	09-08-69
<p>This paper was written for quick comprehension without the use of mathematics. It is divided into two sections. The first section describes the component fundamentals of a hydrostatic transmission. The second section covers the mechanical controls used on vehicles, which have hydrostatic transmissions, with regard to engine throttle, transmission, steering, service brakes, and parking brakes.</p>				
Air-Driven Hydraulic Pumps	R. Chaltry	Applied Power Industries, Inc.	SAE 690793	1969
<p>There is a growing demand today for design improvement in the operation of auxiliary functions on both off-highway and on-highway mobile type equipment. Faster, more efficient operation, better control, and less operator fatigue were the design goals considered in the design of the new AU air pump described in this article. Using the available pneumatic power source presently incorporated in the design of most vehicles today, this efficient, light-weight, low-cost, high-cycling speed intensifier is limited in its application only by the imagination of the vehicle designer.</p>				
Automatic Central Hydraulic Systems for Front Loaders	F. Ratliff	Tyrone Hydraulics, Inc.	SAE 700568	04-14-70
<p>Controlling the cost of excavating and moving a yard of earth is the greatest challenge confronting the earth-moving industry today. This industry, in particular, faces both a shortage of skilled operators and an inflationary wage environment. To increase a skilled operator's efficiency and decrease learning time for new operators, the Tyrone Automatic Central Hydraulic System automatically directs the proper amount of hydraulic power at the proper time to the various functions of the front loader. Hydraulic valving coordinates pump flows for approximately constant lock-to-lock times throughout the cycle regardless of engine rpm and at the same time, controls the interaction of the lift cylinder, bucket cylinder, and transmission disconnect for the fastest possible full bucket loading in both stockpile and virgin bank.</p>				
The Systems Approach to Heavy Truck Steering	K. W. Schipper K. G. Moss	Ford Motor Company	SAE 700880	1970
<p>The systems approach provides a technique that considers all facets of design and validation of a system as a series of dependent sub-systems. This technique involves treating the system in its entirety when establishing the performance parameters and requires that the criteria assigned to each component satisfy total performance. By designing in this objective manner, the system will be optimized and the overall program will be conducted at maximum efficiency.</p> <p>This paper promulgates this process applied to the steering system of a heavy truck with the associated gains in vehicle performance.</p>				
Steering and Braking Systems on the Articulated Motor Grader	L. B. Eberhart	John Deere Dubuque Tractor Works	SAE 710530	04-05-71
<p>The steering and braking systems used on the all-hydraulic JD-570 articulating grader were designed with the safety of the operator in mind. These systems are given priority over the other related hydraulic systems on the grader through the use of a priority valve. An accumulator is provided to store hydraulic energy for the steering and braking systems in the event of a power failure. In addition, the brake valve is capable of acting as a pump to supply pressure oil to the service brakes, if required. A mechanically actuated secondary brake effective on all four tandem wheels is also provided.</p>				



Table 1. Abstracts of the Significant Literature (Cont)

<u>TITLE</u>	<u>AUTHOR</u>	<u>AFFILIATION</u>	<u>SOURCE</u>	<u>DATE</u>
Clark 675 24-cu yd Front-End Loader	G. C. Smith	Clark Equipment Co.	SAE 710719	09-13-71
<p>Our market surveys indicate that large-quarry and mining people, many who own front-end loaders in the 10-12 yd size, are definitely interested in loaders of a much larger capacity. This is due, in part, to increased operator's costs and the need to produce material at a lower cost per ton. The model 675 with 24 cu yd capacity was designed with these thoughts in mind. This paper will discuss the design, testing, and special features of the machine.</p>				
Human Factors Methodology in the Design of the Driver's Workspace in Trucks	P. Kyropoulos	General Motors Corp.	SAE 720293 (ALSO SP-367)	1972
<p>This paper is essentially a set of instructional notes intended for the use by those who want to familiarize themselves with the methodology of human factors as applied to the design of truck cabs. Careful study and use of the references is required if the notes are to be useful. The need for constructing mock-ups and for experiments using typical users as test subjects is repeatedly emphasized. The basic elements of anthropometrics are reviewed. Seeing is treated as the first step in the decision-making process. It is the most important channel of communication between the driver, the vehicle, and the surrounding road and traffic. Similarly, control location and identification is a problem in communication between driver and vehicle. Control forces, seating, and environmental requirements of comfort and alertness are reviewed.</p> <p>Simulation and simulators are treated here as an essential part of experimental aspects of human factors design. The role of mathematical models is examined.</p> <p>A number of exercises accompany the text. The references list 34 texts and papers as well as 9 applicable SAE Recommended Practices. Illustrations are held to a minimum.</p>				
Development of a Hydromechanical Steering Transmission	R. J. Dorgan R. L. Rio D. M. Latson	General Electric Co. General Electric Co. U.S. Army	SAE 720726	09-11-72
<p>The advantages of infinitely variable ratio steering and propulsion for track laying vehicles are well known. Studies and demonstrator programs in the past decade have indicated that the hydromechanical transmission has the most promise of providing infinitely variable ratio for military vehicles. In 1966 the Army launched a program to develop the hydromechanical transmission to "production ready" status. This paper describes that program, the transmission selected, and some of the problems encountered in the transition from the demonstrator stage to one of readiness for military application.</p>				
Advantages of Low-Speed High-Torque Hydraulic Motors when Applied on Farm, Construction, or Industrial Machinery	W. L. Sumpter	Char-Lynn, Eaton Corp.	SAE 720769	09-11-72
<p>Many of the requirements for rotary power on farm, construction, and industrial machinery can be best satisfied by the use of hydraulic motors. Remote mounting capability, unlimited rotation, reversibility, good variable speed control, and small size and weight are some of the general advantages made possible by the use of hydraulic motors.</p> <p>More specifically, low-speed high-torque hydraulic motors offer even more advantages to the product designer. In many cases these motors eliminate the need for gearboxes and reduce the number of other mechanical components, thereby providing increased design flexibility in the end product.</p>				
Hydraulic Steering Control System - A Flow Amplifier Approach	J. B. Waggoner	Caterpillar Tractor	SAE 720802	09-11-72
<p>Smooth, effortless steering systems for large, articulated vehicles enhance their production performance. This paper deals with the complete primary steering system and also brings into focus an approach to the current industry need for a back-up, or secondary steering system. The individual components of both primary and secondary steering systems are discussed in detail from a design and functional standpoint. The overall system performance is then discussed to identify clearly the various component functions and relationships.</p>				



Table 1. Abstracts of the Significant Literature (Cont)

<u>TITLE</u>	<u>AUTHOR</u>	<u>AFFILIATION</u>	<u>SOURCE</u>	<u>DATE</u>
Hydrostatic Steering Designed for Large Off-Highway Vehicles	J. L. Rau	TRW, Inc. Ross Gear Division	SAE 720803	09-11-72
<p>Simplified power steering control of large off-highway vehicles still remains a formidable problem for steering system designers. Several hydraulic power steering mechanisms presently prevail with varying envelope and performance features compromised for off-highway application.</p> <p>This paper describes the first low-cost positive displacement-type hydrostatic steering unit especially designed for the large off-highway vehicle industry. The basic features of the HGB hydrostatic steering system are discussed relative to set goals in each major design area. It is shown that the HGB Hydraguide meets the general requirements for a simplified high-flow hydrostatic steering unit adaptive to the off-road construction and earthmoving machine.</p>				
The Truck Steering System From Hand Wheel to Road Wheel	J. W. Durstine	Ford Motor Company Truck Operations	SAE 730039 (ALSO SP-374)	1973
<p>This paper covers the subject of commercial vehicle manual and power steering system design and development from the total vehicle viewpoint. It includes a discussion on the interrelationship of cab package, front suspension, and tires on truck steering as well as a description of the pertinent steering system characteristics. The function of the various steering system components are described as reference for system design and selection of industry available hardware for a specific application. The topics are presented in a manner which explains the logic of total steering system design from the initial stage of vehicle concept through the initial package proposal.</p>				
Articulated Loader Stored Energy Steering System	L. Becker	Hydreco Division	SAE 730768	09-10-73
<p>With the emphasis on safety steering, a steering package has been designed to achieve the safety requirements in a stored energy system. This paper reports the application of an accumulator-unloading valve type of steering system on an articulated loader. The paper concludes that the closed-center steering system exhibits these advantages over an open-center steering system; simplified circuit, potential cost savings, built-in safety steering capability, and improved metering of a closed-center valve.</p>				
A Reliability Oriented Approach to the Design of Off-Highway Steering Systems	D. Webb	Westinghouse Air Brake Co.	SAE 730769	09-10-73
<p>Four different off-highway truck hydraulic steering systems with varying complexity are presented. The reliability of each type of system is compared showing the effects of redundancy of components. The importance of system configuration is brought out to offset the adverse effects of a low reliability component.</p> <p>The advantages of a stored energy system in providing an emergency steering capability and in reducing the size of the pump are discussed.</p>				
Hydrostatic Steering with Power-Beyond Capability	J. L. Rau	TRW, Inc. Ross Gear Division	SAE 740435	04-23-74
<p>Integration of the power steering function into varied control hydraulic systems of mobile equipment requires an adaptive steering valve. The new Ross 5-line Hydraguide meets the criteria and introduces unique flexibility to steering circuit design.</p> <p>This paper highlights a positive displacement-type hydrostatic steering unit with an integral priority steering feature and an additional fifth port connection for a secondary hydraulic function. This concept of power-beyond capability in hydrostatic steering is discussed and its versatility demonstrated. It is shown that the power-beyond Ross Hydraguide provides simplified hydraulic circuitry and increased power utilization at moderate cost for off-highway machinery.</p>				

Table 1. Abstracts of the Significant Literature (Cont)

<u>TITLE</u>	<u>AUTHOR</u>	<u>AFFILIATION</u>	<u>SOURCE</u>	<u>DATE</u>
Maintenance and Design Problems with Current Earthmoving Machines	C. E. Sanders	Green Construction Company	SAE 740448	04-23-74
<p>Contractors continue to purchase manufacturers' machines which are designed for an intended operation, although such machines cause operators, mechanics, and owners undue downtime and increased operation and maintenance cost. Some of the recurring problems identified by contractors' personnel are included in this presentation.</p>				
Describing the Driver's Work Space: Eye, Head, Knee, and Seat Positions	R. W. Roe	General Motors Corp.	SAE 750356	02-24-75
<p>The SAE Controls Reach Study provided the opportunity to obtain a considerable amount of driver work space data in addition to hand and foot reach. A side-view film recording was made of each test subject assuming a driving attitude and looking straight ahead. Of concern were locations for the driver's eyes, top of head, back of head, knee, and seat.</p> <p>These data were combined with other data previously reported to develop tools that will aid the designer in describing space and comfort requirements for seated drivers and passengers in automotive packages. Fixed-seat eye ellipses, head locations, shin-knee locations, and preferred seat positions are described.</p>				
Controls Reach - The Hand Reach of Drivers	D. C. Hammond D. E. Maurer L. Razgunas	Ford Motor Company Environmental and Safety Research Office	SAE 750357	02-24-75
<p>This report describes a series of three-dimensional boundaries beyond which it is confident that at least 95% of the drivers of the United States population can reach and operate a simple three-finger-grasped control. Consideration is given to a reach task when drivers are restrained by a nonextending shoulder belt and when they are unrestrained. The background data used to develop these boundaries were collected in the SAE Controls Reach Study in June -August 1971 in which over 250 subjects were measured in three test fixtures representing a sports car, passenger car and a heavy truck. Finger-grasped reach was recorded to 40 locations in front of the driver.</p>				
Tire Induced Steering Pull	R. W. Topping	B. F. Goodrich Co.	SAE 750406	02-24-75
<p>A theory of vehicle steering pull, created by asymmetrical tire cornering properties, is developed. It is validated with free control data obtained on the road.</p> <p>The effects of tire lateral force and aligning torque asymmetries on a car's straight line stability are analyzed for both fixed and free control. Equations for front axle lateral force, steering system moment, and sideslip angle are derived. They are based on tire properties and certain assumptions about the car's characteristics.</p> <p>This theory is validated using data obtained in open road testing. The test techniques, as well as alternate ones, are described. In addition, the relationships between actual front axle force and axle conicity force, ply steer force, and lateral force offset are analyzed. It is found that front axle conicity force correlates very strongly with a more accurate theoretical prediction. The axle force predicted by tire conicity force is somewhat low.</p>				
Steering Analysis of a Three-Axle Vehicle	D. J. Olson L. J. Hunsader	International Harvester Company WABCO Construction & Mining Equipment Group	SAE 750551	04-15-75
<p>An analysis of the forces acting on a three-axle vehicle resulted in a computer program that calculated tire forces and minimum turning circle diameter.</p> <p>The computer program is a valuable design tool because changes in steering geometry can be quickly evaluated. The effect on tire forces and turning circle diameter can be readily determined.</p>				



Table 1. Abstracts of the Significant Literature (Cont)

<u>TITLE</u>	<u>AUTHOR</u>	<u>AFFILIATION</u>	<u>SOURCE</u>	<u>DATE</u>
Design Concepts of the JD770 Motor Grader	L. L. Williams	John Deere Dubuque Works	SAE 750564	04-15-75
<p>In the overall concept of a motor grader, many requirements must be established and met to produce a machine that will efficiently perform the work for which it was intended.</p> <p>Some of the major design concepts, features and specifications of the new John Deere JD770 Motor Grader are discussed in this paper.</p>				
Earthmoving Truck History and Progress	R. H. Kress	Kress Corporation	SAE 750579	04-15-75
<p>Until approximately 50 years ago horses and manpower were considered the best means for earthmoving. Progress from this point came in the late 1930s as off-highway trucks began to replace on-highway trucks. The development of engines with more horsepower moved the industry ahead. Today earthmoving is made more complex for we must consider not only the advances in earthmoving equipment, but also if equal advances have been made in auxiliary equipment and manpower to allow maximum efficiency.</p>				
Design Concepts of the 400 Series Scrapers	R. A. Wade	International Harvester Company, Pay Line Division	SAE 750779	09-08-75
<p>A family of four scrapers has been developed to provide operational versatility while emphasizing physical commonality. The wide variety of operational requirements encountered by scrapers, were considered and related to the basic type of scraper best suited for the particular conditions.</p> <p>Many vehicle systems were designed to provide maximum commonality between the single and dual engine, open bowl and elevating machines. Various new features were developed to improve vehicle performance and ease of operation.</p>				
Load-Sensitive Hydrostatic Steering - A New Approach	J. L. Rau	TRW, Inc. Ross Gear Division	SAE 750806	09-08-75
<p>Load-sensitive hydraulic control systems have demonstrated new potential high efficiency levels. Mobile equipment designs which widely utilize open and closed center circuits are being adapted to total centralized load-responsive stand-by systems to curtail fuel consumption and operating costs.</p> <p>This paper outlines previous art in steering systems and highlights the design concepts required to adapt the steering function to load sensitive variable flow-pressure circuitry. Since the steering function power demands are normally low for corrective maneuvers, it is ideally suited to the environment of a central load-sensitive system. The general concept of a load-sensing steering valve and its relative design role to the other system components will be developed, emphasizing standard metering load-sensing technology. The possible new "feathered" and "absolute" type systems are introduced.</p>				
Controlling Variable Displacement Hydraulic Pumps for Energy Conservation	A. Myers	Sundstrand Corp. Hydro-Transmission Div.	SAE 750807	09-08-75
<p>The possible causes of hydraulic power losses in both closed and open loop hydraulic systems are discussed. The means of minimizing these losses with the proper choice of closed versus open loop systems and with maximum utilization of variable displacement pump controllability are discussed. Also discussed are means of reducing prime mover size with pump power limiting controls to increase power generation efficiency. Examples are analyzed to illustrate the energy saving potential of closed loop pressure control, open loop pressure and flow compensation, and closed or open loop pump power limiters.</p>				



Table 1. Abstracts of the Significant Literature (Cont)

<u>TITLE</u>	<u>AUTHOR</u>	<u>AFFILIATION</u>	<u>SOURCE</u>	<u>DATE</u>
21 Cubic Yard 580 PAY Loader	P. L. Ajwani	International Harvester Company, Pay Line Division	SAE 750817	09-08-75

To effectively utilize larger trucks (85 ton and up), open-pit mines and quarries need a larger front-end loader with high reliability and performance. This paper describes the design approach and tests carried out to design 21 cubic yard 580 PAY loader to meet these requirements.

Long fatigue life of structures was obtained by use of full penetration welds. New concept for power control was designed to effectively distribute power between hydraulics and drive train. Spring applied - pressure released brakes were designed into the axle. Tests were carried out in our laboratory and proving grounds to determine performance and reliability.

Front Brake Interactions with Heavy Vehicle Steering and Handling During Braking	T. D. Gillespie	Ford Motor Company	SAE 760025	02-23-76
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The increased braking performance required on air-brake equipped commercial vehicles by the Federal Motor Vehicle Safety Standard 121 results in vehicles with higher front brake torque capacity and greater deceleration capability. Using a simple analytical model, certain mechanisms by which handling during braking is influenced by tire characteristics, load transfer during braking, steering system characteristics, brake imbalance, and other factors are demonstrated. In addition, analysis of the steering system shows how steer angle deviations arise from braking and lateral forces acting against compliance of the steering linkage, and the influence of caster geometry on these deviations.

To investigate certain quantifiable characteristics of handling performance, the HSRI Directional Response Computer Program for predicting the longitudinal and directional response behavior of trucks was modified to include the effects of a compliant steering system subject to the force and moment inputs of the front tires. Measurement of bias ply truck tire force and moment characteristics for use in the computer simulation revealed that tire aligning torque characteristics reverse in direction at high braking levels and may dominate the effect of geometric caster built into the steering system.

Studies utilizing the modified program indicate that (a) no vehicle will stop perfectly straight without driver steering corrections because of steer angle deviations and (b) the steering reactions fed back to the steering wheel during braking may reverse direction with antilock brake cycling, largely because of the reversal of tire aligning torques. A relationship between these steering reactions and front brake torque level is shown.

Development of a 350 Ton Haulage Truck	G. Felix	General Motors of Canada, Ltd.	SAE 760408	04-26-76
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The development of "Off-Highway" rear dump haulage trucks with ever larger payload capacities is governed by the availability of suitable prime movers, transmissions and tires.

The adaptation of existing diesel-electric locomotive prime movers and transmissions to the requirements of "Off-Highway" truck applications and the availability of large capacity tires has resulted in the development of a rear dump haulage truck with a 350 ton payload capacity.

This paper describes the equipment selection process and highlights some of the product design features.

Diverting and Unloading Hydraulic Systems Earthmoving Applications for Energy Conservation	J. R. McBurnett	Tyrone Hydraulics, Inc.	SAE 760417	04-26-76
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The manufacturer of earthmoving equipment is continually seeking to maximize his machine's productivity and reliability in order to maintain his competitive position in the market. In this period of "energy consciousness", he further endeavors to have a machine that is not only highly productive but is also as energy-efficient as possible. This paper presents a brief look at an energy-efficient system utilizing fixed displacement pumps which are controlled by a diverting and unloading valve.

Table 1. Abstracts of the Significant Literature (Cont)

<u>TITLE</u>	<u>AUTHOR</u>	<u>AFFILIATION</u>	<u>SOURCE</u>	<u>DATE</u>
Closed Center Hydraulic System For An Articulated Motor Grader	W. I. Nelson J. Dezelan	Caterpillar Tractor Company	SAE 760429	04-26-76
<p>THE HYDRAULIC SYSTEMS for the Caterpillar "G" Series Motor Graders were designed to provide for maximum operator comfort, ease of operation, and optimum control of the vehicle and implements. The use of high pressure closed center systems on these machines produces rapid system response and high hydraulic horsepower to the implement cylinders and motors, and operates with minimum size control components. Components were designed to meet specific system requirements for functional performance, reliability of operation, size and placement on the machine. System goals were met through the use of a variable displacement pressure compensated pump, controlled flow four-way implement valves, and a hydrostatic steering system.</p>				
The Effects of Government Regulations in British Columbia	W. F. Holmes	Finning Tractor & Equipment Co., Ltd	SAE 770517	04-18-77
<p>This paper will deal with some of the effects of government regulations in the province of British Columbia. It will also explain how the regulations have been derived and what purpose they serve.</p>				
Design Considerations for the Goodbary Bottom Dump Haulage Trucks	E. R. Goodbary	Goodbary Equipment Co.	SAE 770548	04-18-77
<p>"Design Considerations for the Goodbary Bottom Dump Haulage Trucks" accepts the conclusions of previous investigations indicating strong inherent advantages of the two-axle, bottom-dump rear-axle powered unit, utilizing two wheel motors, and presents a summary of a comparative study between a single tire application and a dual tire application, further concluding that single tire mounting is the only functionally sound and economically feasible choice. In the process of reaching this conclusion, included are a number of related design and operational considerations of off-road haulage equipment which will provide the greatest return for the end user.</p>				
The Caterpillar 988B Wheel Loader	S. B. Adams	Caterpillar Tractor	SAE 760648	09-13-76
<p>A new Caterpillar Wheel Loader has been developed as a replacement for the current production 988. This paper provides a review of the machine objectives, summarizes the development program, and provides an introduction to the major features.</p>				
Simulation of Motor-Scraper Overturns	S. Okuno G. E. Rehkugler	Komatsu, Ltd. Cornell University	SAE 770703	09-12-77
<p>A mathematical model was developed to simulate three-dimensional motor-scraper overturns. From the results data necessary for the ROPS (Roll-Over Protective Structures) tests, such as, kinetic energy and the positions and velocity of the motor-scraper are obtained. The output from the simulation program were visualized by using graphic displays or plotting.</p>				
Steiger Tractor's Tiger III, ST-450	D. Majkrzak	Steiger Tractor Co.	SAE 770707	09-12-77
<p>A new 450 HP four-wheel drive articulated farm tractor has been developed by Steiger Tractor Inc. This paper summarizes the design, development, and testing of this unit along with an overview of the systems. Several frame designs different from production tractors were used along with more operator convenience and comfort ideas in the new wider ROPS cab. The vehicle combines the performance of a high torque rise engine with the advantages of a powershift transmission with torque converter.</p>				

Table 1. Abstracts of the Significant Literature (Cont)

<u>TITLE</u>	<u>AUTHOR</u>	<u>AFFILIATION</u>	<u>SOURCE</u>	<u>DATE</u>
J I Case Model 2870 Four-Wheel Drive Tractor	D. J. Svendsen	J. I. Case Co.	SAE 770708	09-12-77
<p>The Case Model 2870 is a whole new tractor designed to meet customer demands. This paper gives a description of the new designs which went into its production.</p>				
Integration of Component Design for a 170 Ton Off-Highway Truck	M. H. Naft	Euclid Inc.	SAE 770741	09-12-77
<p>The purpose of this paper was to explain the design of the components of the Euclid 170 ton capacity off-highway rear dump truck. The unique aspects of this Euclid design flowed from a threefold perspective: 1. box-section frame construction; 2. liquid spring suspension; 3. horizontal body-side stiffeners.</p> <p>Since overall vehicle performance and durability were dependent on the harmony which must be developed between major components, particular emphasis was given to an examination of the interrelationships of suspension, frame, and body.</p> <p>The vehicular characteristics indicated that the suspension system with liquid springs, while yielding a good ride also played an important role in minimizing frame and body distress. In addition, good suspension would not be possible without the proper geometrical orientation the frame design afforded. Finally, loading and haulage were seen to be dependent not only upon the body in which the load is contained, but also upon the suspension which absorbed the input shocks and the frame which eventually supported both body and load.</p>				
Steering Diagnosis - A Study of Degraded Components Affecting In-use Vehicle Handling	M. S. Merrill	Clayton Manufacturing Company	NTIS PB-188-057 NTIS PB-188-058 (DOT Study)	1968
<p>The forthcoming use of Periodic Motor Vehicle Inspection as a means of lessening accidents requires the establishment of in-use vehicle components needing inspection and the standards of rejection. This contract initiates a program which physically studies the adverse effects of degraded automobile chassis components on directional stability and control.</p>				
Vehicle-In-Use System Safety Analysis - Volume I: Summary Report	Booz-Allen Staff	Booz-Allen Applied Research, Inc.	NTIS PB-197-301 (DOT Study)	09-10-70
<p>This study was undertaken to perform a detailed vehicle safety analysis to identify and rank vehicle failure modes according to their criticality. Criticality is defined as the product of probability of occurrence of a fault times its potential effect in accident causation.</p> <p>The analysis of failure paths and modes was accomplished through development of detailed fault logic diagrams for five defined vehicle systems: Brakes, Steering, Power Management, Visibility and Human Impairment Related Components. Fault probability data was reviewed from accident records data, diagnostic data statistics, and leasing fleet operations and maintenance records. The leasing fleet data was used as the primary source of probability data for the criticality computations. An effects scale was developed using the "Delphi" technique to solicit expert opinions from a number of safety personnel, and specific faults were placed on this scale. Criticalities were then computed for all faults for which probability data were available.</p> <p>Conclusions included a rank ordered list of component fault criticalities by system, and a series of recommendations were made to improve vehicle safety through criticality reduction. Recommendations were also made for further research required to establish the feasibility or practicality of safety improvement proposals.</p> <p>A bibliography is included citing 204 references on related subjects, and a review is also included of previous DOT studies on the subject of vehicle-in-use safety.</p>				



Table 1. Abstracts of the Significant Literature (Cont)

<u>TITLE</u>	<u>AUTHOR</u>	<u>AFFILIATION</u>	<u>SOURCE</u>	<u>DATE</u>
Vehicle-In-Use System Safety Analysis - Volume V: Safety Analysis of Steering System	Booz-Allen Staff	Booz-Allen Applied Research, Inc.	NTIS PB-197-305 (DOT Study)	09-01-70

This report presents the results of a study undertaken for the National Highway Safety Bureau to analyze the steering system of a typical American-made vehicle in use, to determine steering system components and parameters critical to highway safety, and to recommend areas for the development of steering system safety standards or additional research.

Effects of Steering & Suspension Component Degradation on Automobile Stability and Control. Part I. Summary Report	K. D. Bird	Cornell Aeronautical Laboratory, Inc.	NTIS PB-198-464 (DOT Study)	01-01-71
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The objectives of this program were to determine, through vehicle testing, how various types of steering and suspension degradation affect objective measures of vehicle performance and to determine cost effective methods of inspection for these systems.

The major results of four tasks are briefly described. A literature survey of over 150 related articles was made but uncovered little information of direct use. A test plan involving six vehicles and nine driving tasks was devised for investigating the influences of impairments of suspension and steering components on performance. Test results provided a firm foundation of quantitative measurements for evaluating these relationships. These results, together with supporting studies of the design and operation of components of interest in this program, were used as the basis for recommendation of cost-effective inspection requirements.

Effects of Steering & Suspension Component Degradation on Automobile Stability and Control. Part II - Technical Report - Volume 1 - Literature Review	R. D. Vergara	Cornell Aeronautical Laboratory, Inc.	NTIS PB-194-465 (DOT Study)	01-01-71
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The objectives of this program were to determine, through vehicle testing, how various types of steering and suspension degradation affect objective measures of vehicle performance and to determine cost effective methods of inspection for these systems.

This volume is concerned with a literature survey of related topics. Over 150 articles are reviewed. They cover vehicle performance, degradation of in-service components and system, current methods of inspection and diagnosis, life expectancy and failure data, and safety implications of degraded systems. Particular attention is given to earlier NHTSA-sponsored work in this general area.

Effects of Steering & Suspension Component Degradation on Automobile Stability and Control. Part II - Technical Report - Volume 2 - Test Plan	M. R. Belsdorf	Cornell Aeronautical Laboratory, Inc.	NTIS PB-198-466 (DOT Study)	01-01-71
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The objectives of this program were to determine, through vehicle testing, how various types of steering and suspension degradation affect objective measures of vehicle performance and to determine cost effective methods of inspection for these systems.

This volume is concerned with test plan development. A test car complement covering a wide range of manufacturers, body and frame designs, and steering and suspension system layouts is described. Details of courses and procedures for nine driving tasks especially devised for the evaluation of the effects of component impairments on performance are given. Instrumentation requirements for these tests are outlined. The principle components which were investigated are identified and the quantitative levels of impairment which were used in the test program are described.

Table 1. Abstracts of the Significant Literature (Cont)

<u>TITLE</u>	<u>AUTHOR</u>	<u>AFFILIATION</u>	<u>SOURCE</u>	<u>DATE</u>
Effects of Steering & Suspension Component Degradation on Automobile Stability and Control. Part II - Technical Report - Volume 3 - Test Results	M. R. Belsdorf	Cornell Aeronautical Laboratory, Inc.	NTIS PB-198-467 (DOT Study)	01-01-71

The objectives of this program were to determine, through vehicle testing, how various types of steering and suspension degradation affect objective measures of vehicle performance and to determine cost effective methods of inspection for these systems.

This volume is concerned with test results. Some three thousand full-scale test runs were performed with selected combinations of test vehicle, driving task, type of impaired component, and degree of impairment. Results are given for the effects of degraded shock absorbers, ball joints, steering systems (free-play and misalignment), steering dampers, and roll bars on performance. Measurements are given in terms of both man-machine system behavior and control input requirements. It is shown that good discrimination among conditions can be achieved with the selected tasks.

Effects of Steering & Suspension Component Degradation on Automobile Stability and Control. Part II - Technical Report - Volume 4 - Inspection Requirements	R. S. Rice	Cornell Aeronautical Laboratory, Inc.	NTIS PB-198-468 (DOT Study)	01-01-71
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The objectives of this program were to determine, through vehicle testing, how various types of steering and suspension degradation affect objective measures of vehicle performance and to determine cost effective methods of inspection for these systems.

This volume is concerned with inspection requirements. The results of a full-scale test program which produced quantitative measures of the component impairment-performance relationships and of examinations of actual hardware to identify the most likely courses of degradation are used to establish recommendations for cost-effective methods of inspection of steering and suspension systems. Current inspection techniques in general use are reviewed. These are used as reference points for recommendations on levels of acceptability in MVI.

Effects of Steering & Suspension Component Degradation on Automobile Stability and Control. Part II - Technical Report - Volume 5 - Appendices	M. R. Belsdorf	Cornell Aeronautical Laboratory, Inc.	NTIS PB-198-469 (DOT Study)	01-01-71
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The objectives of this program were to determine, through vehicle testing, how various types of steering and suspension degradation affect objective measures of vehicle performance and to determine cost effective methods of inspection for these systems.

This volume contains background discussions on a variety of subjects with special significance to the program. Design features and operating characteristics of many examples of shock absorbers, ball joints, steering systems, rubber elements, suspension layouts, and alignment characteristics are described. Probable modes of degradation and failure are outlined in the framework of identifying appropriate inspection procedures. A description of the digital computer simulation of an automobile used in support of the development of the test plan is given. Means for quantifying road holding capability are described.

Table 1. Abstracts of the Significant Literature (Cont)

<u>TITLE</u>	<u>AUTHOR</u>	<u>AFFILIATION</u>	<u>SOURCE</u>	<u>DATE</u>
Maintainability & Repairability of Vehicles-In-Use - Volume II - Technical Report	Booz-Allen Staff	Booz-Allen Applied Research, Inc.	NTIS PB-202-532 (DOT Study)	06-01-70

In this study the problems and requirements for maintenance and repair of safety critical vehicle components and systems are studied for vehicles less than 8,000 lbs. Solutions which minimize tasks and reduce costs, are presented. Repair industry problems, related to mechanic skill requirements are discussed and recommendations are presented. A parts failure rate data format is developed and a detailed three year summary of maintenance and repair data from a major leasing fleet is tabulated.

The study concludes that the major vehicle design factors that affect maintenance and repair are accessibility, complexity, durability and diagnosis. It is estimated that a 30 percent reduction in safety related maintenance and repair can be achieved by design changes which have minimal impact on initial cost.

Human Force Considerations in the Failure of Power Assisted Devices	B. F. Pierce W. E. Woodson P. H. Selby	Man Factors, Inc.	NTIS PB-222-851 (DOT Study)	07-01-73
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This study is concerned with determining the physical effort automobile drivers can exert on brake pedals and steering wheels when power assist systems have failed with the resultant data serving as a basis for motor vehicle standards development and compliance.

Industrial Engineering Study of Hazards Associated with Surface Coal Mines	T. Barry & Associates Staff	Theodore Barry & Associates	NTIS PB-235-927 (USBM Study)	06-24-74
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The purpose of this study was to identify the type of mining accidents that are occurring in strip mines, auger mines, mechanical preparation plants, and on the surface of underground mines. The hazards present and the direct causes of the accidents were identified, and practical solutions were recommended to reduce their occurrence. Greater emphasis should be placed on the following 10 recommendations to achieve quick safety improvements at a relatively low cost: 1. Inspection of front-end loaders for mechanical defects before and during each shift; 2. Highwall inspection and scaling; 3. Falling object protection for loaders and dozers; 4. Automation of railroad car dropping operations; 5. Inspection of dozers for mechanical defects before and during each shift; 6. Periodic inspection of work areas during front-end loader operations; 7. Truck driver education and training program; 8. External communication systems on shovels and draglines; 9. Adequate handholds, steps, and ladders on all mining equipment; 10. Insulated grounded rod for touching a previously energized high-voltage terminal or device.

Proceedings - Second International Conference on Vehicle Structural Mechanics - Southfield, Michigan	---	SAE Sponsored	SAE-P71	04-18+20-77
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A collection of the papers presented at the referenced symposium. The papers presented cover topics in collision and plasticity, structural design, analytical techniques, structural optimization, and component analysis and design. The treatment of the topics is theoretical. Techniques in mathematical modeling are described.

Table 1. Abstracts of the Significant Literature (Cont)

<u>TITLE</u>	<u>AUTHOR</u>	<u>AFFILIATION</u>	<u>SOURCE</u>	<u>DATE</u>
Fundamentals of Machine Operation - Tractors	C. R. Pearsal	John Deere Co.	John Deere	1974

This volume presents a comprehensive description of agricultural tractors; their evolution; construction, operation, and maintenance. Topics covered include design progress, engines, power trains, hydraulics, other components, controls and instruments, attaching and removing auxiliary equipment, field operation, safety and transport, maintenance and storage, and trouble shooting. The subject treatment is directed towards operator training rather than machine design.

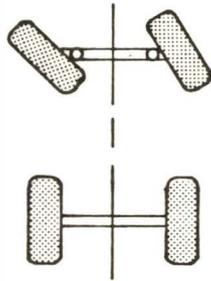
SECTION 3.0
STEERING SYSTEM TECHNOLOGY

3.1 BASIC METHODS OF STEERING

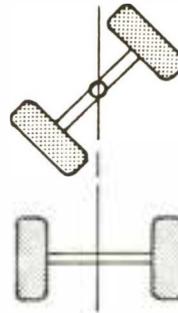
In simplest form, the basic purpose of any steering system is to guide or direct the motion of a vehicle. However, the development of complex, self-propelled vehicles commonly used in today's surface mining industry has complicated and added additional requirements to the basic purpose of a steering system. Satisfying the requirements for efficiency, reliability, and safety is proportional to the complexity of the vehicle and the method of steering used.

During the evolution of vehicles from simple wagons and carts to the complex self-propelled vehicles of today, various steering methods have been attempted. The following discussion briefly describes five of the methods that can be found on today's surface mining equipment. Figure 1 shows representations of these methods.

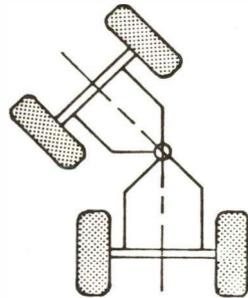
- Ackerman Steering. This method employs unequal angle of rotation of a vehicle's steered wheels in a horizontal plane about a vertical axis in order to negotiate course changes about a common center of rotation for all four road wheels. This method has been used almost exclusively on American-made motor vehicles since 1907. (See Figure 1A.)
- Fifth Wheel Steering. The front and/or rear axles are mounted to the vehicle by a pivoting or rotating joint (fifth wheel). The



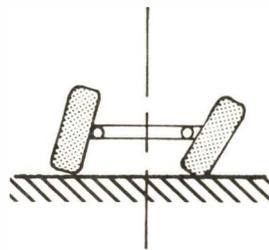
(A) ACKERMAN



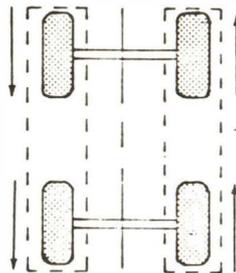
(B) FIFTH WHEEL



(C) ARTICULATED



(D) CAMBER



(E) VARIABLE DRIVE

Figure 1. Basic Steering Methods

road wheels remain perpendicular to the axle centerline as the axle is rotated to change the vehicle course. This method is usually employed on towed vehicles but is used to a limited extent on self-propelled vehicles. (See Figure 1B.)

- Articulated Frame Steering. The vehicle is articulated at the centerline and is allowed to bend as a result. The road wheels are pushed or pulled tangent to the arc described by the intersection of lines perpendicular to the front and rear wheels. (See Figure 1C.)
- Camber Steering. The road wheels are cambered or leaned. The vehicle will steer around the point described by the intersection of the road wheel spindle and the ground. (See Figure 1D.)
- Variable Drive Steering. The road wheels on one side of the vehicle are driven at a different speed than those on the opposite side. This imparts a turning moment to the vehicle. Also, one set of wheels may be braked or reversed to accomplish this action. This method of steering is normally found on tracked vehicles but can also be found on wheeled vehicles. (See Figure 1E.)

It should be noted that the steering methods just described are not all inclusive of the methods used. There are some vehicles that use modifications of these basic methods and still others that have a combination of them.

3.2 BASIC STEERING GEOMETRY

As might be evident from the discussion on basic steering methods, there are particular geometries associated with each method. Certain elements of a particular steering geometry determine certain operating characteristics for both the steering system and the vehicle. A mining vehicle's steering geometry can affect such things as the minimum turning radius, wheelbase, load distribution, maximum safe operating speed and even the wear rate of tires.

One basic geometric element common to any method of steering is the vehicle's turning center (see Figure 2). For the steering methods previously discussed, except camber and

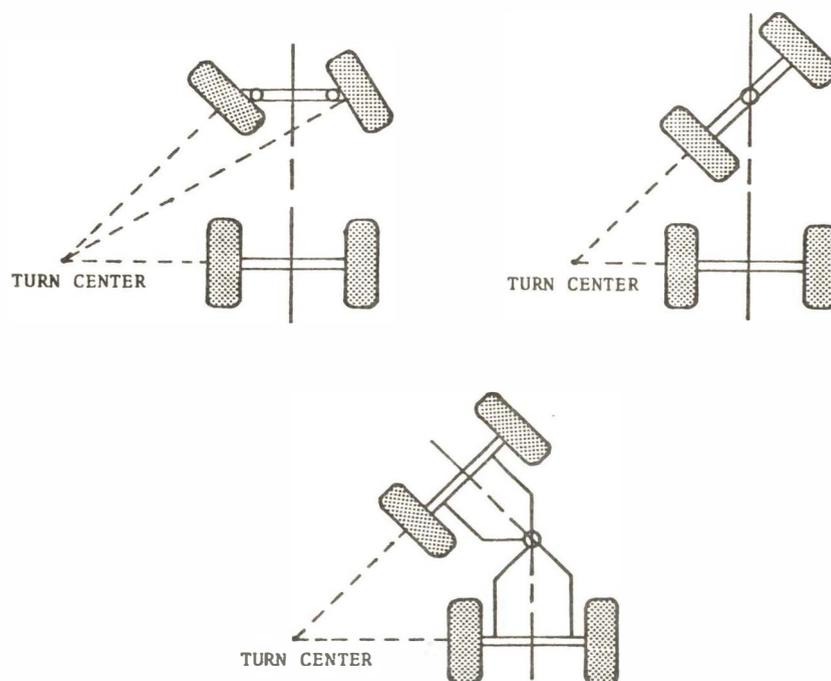


Figure 2. Turn Center Location (Ackerman, Fifth Wheel and Articulated)



variable drive steering, the theoretical turning center is determined by the intersection of lines drawn perpendicular from the front and rear wheel's center of rotation.

For camber steering the turning center is determined by the intersection of lines drawn from the wheel's center of rotation, perpendicular to the wheel camber or lean angle, and the ground surface (see Figure 3).

For the variable drive or tracked steering method, the turn center is theoretically located at the intersection of lines drawn from the alternate front and rear wheel's center of rotation. However, this turn center, as described, can only be achieved when the wheels (or track) on one side of the vehicle are driven at an equal and opposite rate than those on the other side. For any other condition the turn center could be located anywhere within the shaded area shown in Figure 4, depending on the driving wheel's speed and direction.

Two important vehicle operating parameters can be determined from the turn center. These parameters are the vehicle's minimum turning radius and the amount of tire slippage during a turn.

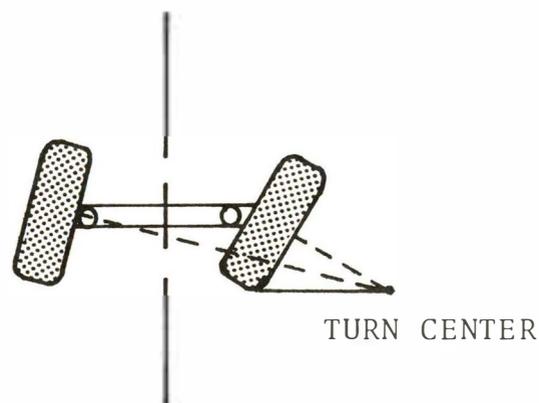


Figure 3. Turn Center Location (Camber)

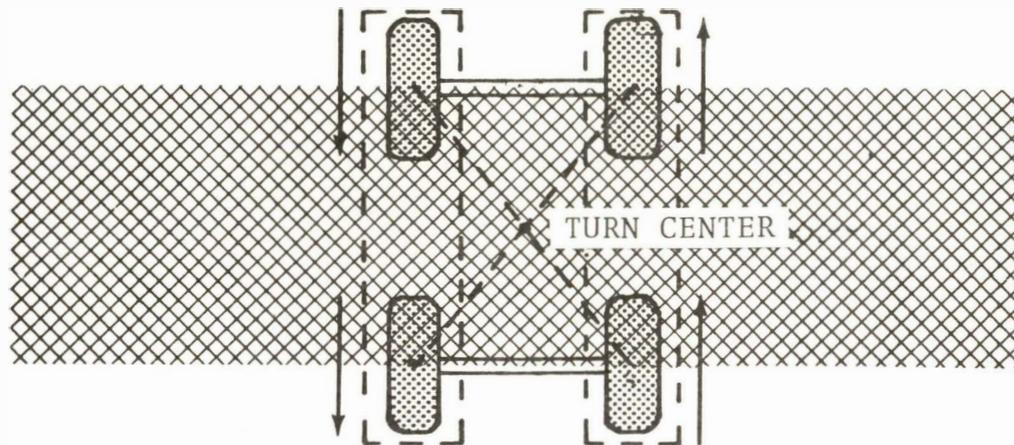


Figure 4. Turn Center Location
(Variable Drive)

A vehicle's minimum turning radius is described as the radial distance from the turn center to the centerline of the farthest wheel being steered to the limit (see Figure 5). This determines the minimum surface area (turning circle) needed for a vehicle to make a complete turn without interruption.

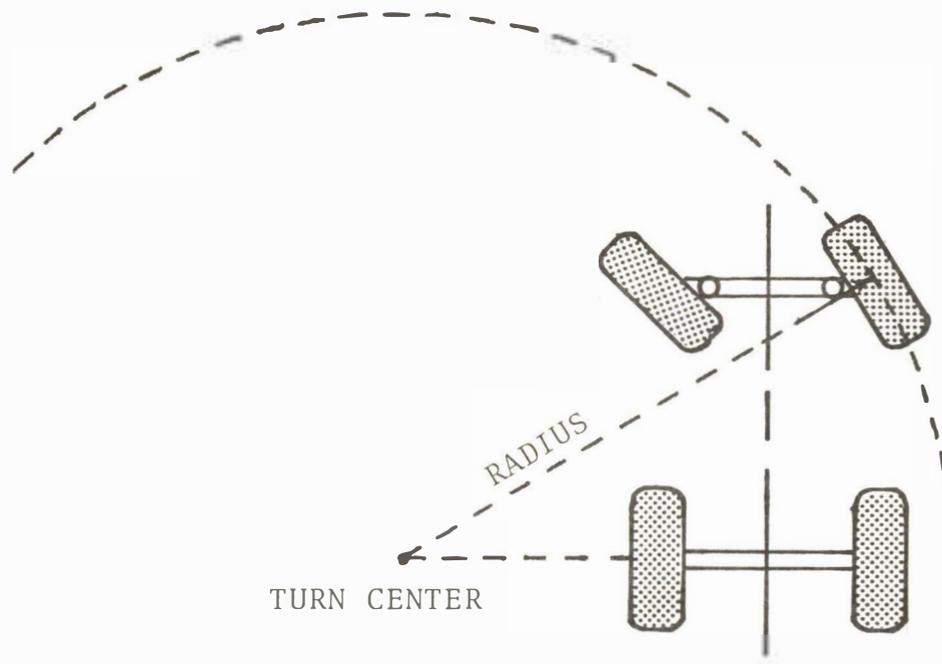


Figure 5. Minimum Turning Radius

The other operating parameter affected by the turn center is the amount of tire slippage or skidding that will occur during a turn. Previous discussion has shown how the turn center is determined (see Figures 2, 3, and 4). In that discussion the word "theoretical" was used to refer to the location of the turn center. This is because for all the steering methods described, the actual turn center will not coincide exactly with the theoretical turn center throughout the turn. This is especially true for a sharp turn.

There are two main reasons for this difference in turn center location. The first is the fact that the tire of a road wheel does not rest on a single point on the road surface. Instead, the tire rests on an area of the road surface. The size of this area will depend on such factors as tire size (diameter and tread width), tire inflation and the load applied to the tire. As a result, the actual turn center is no longer a single point. Graphically, it now becomes an area defined by the intersection of lines drawn perpendicular from the areas of tire and road surface intersection.

The second reason for the turn center being "theoretical" is that a tire's natural rolling tendency is in a straight line which becomes tangent to the arc described by the turn radius during a turn (see Figure 6). The road tires do not experience pure rolling motion but rather, must continuously slip on the road surface in order to follow the turn arc.

There are various factors that affect the degree to which a tire will slip and also the amount of tire wear resulting from the slipping. Some of these factors are: the steering method used (Ackerman producing the least slippage and variable drive having most; variable drive is sometimes called "skid steering"); the vehicle's wheel base; the turn radius; the tire size; the load on the tires; the vehicle speed; and the road surface composition.

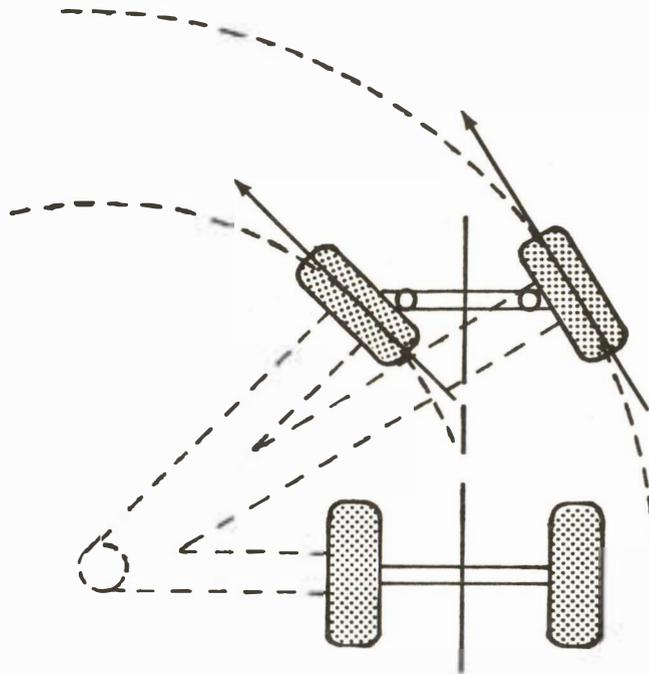


Figure 6. Tire Slippage
During Turn

In addition to the basic geometry just discussed, the Ackerman steering method has some particular geometric aspects associated specifically with it. In the brief description of the Ackerman steering method it was stated: "This method employs unequal angle of rotation of a vehicle's steered wheels...." This is accomplished by the use of a linkage system between the steered road wheels and the steering gear. Figure 7 shows the basic geometric aspects of this linkage system for a vehicle making a left turn.

The inside wheel will rotate through angle α , while the outside wheel will rotate through angle β . This allows the wheels to travel at the same relationship with their respective turn circles described by radii from the turn center and the wheel center lines.

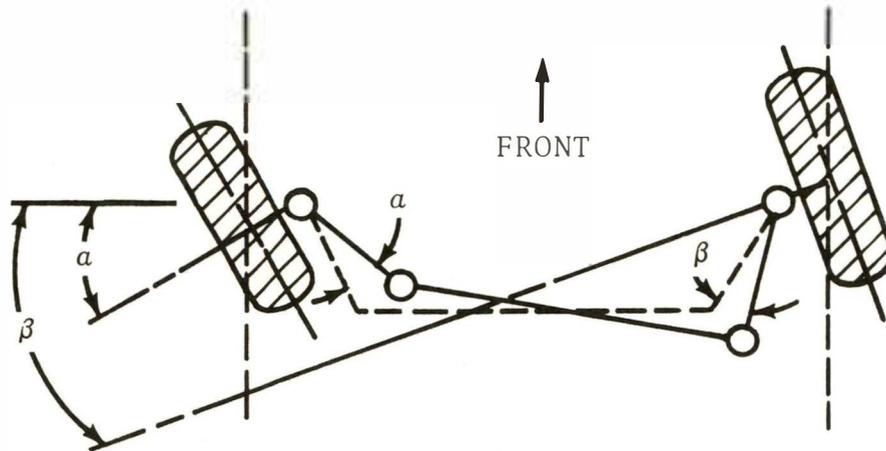


Figure 7. Basic Ackerman Linkage

The remaining geometric aspects associated with Ackerman steering are best explained by briefly describing the six parameters which control the geometry. It should be understood that the interrelationships of these parameters are quite complex and change with changes in vehicle attitude and loading. Because of the complexity, modern truck and auto steering systems are routinely computer designed and modeled so that the geometry may be observed throughout the full range of static and dynamic loading conditions. This discussion will be limited to a brief description of the following parameters:

- Caster. The inclination of the vehicle's wheel pivot in the fore and aft plane of the vehicle is called "caster." Typically the top of the wheel pivot (commonly called the king pin) is inclined towards the rear of the vehicle. The center of the road wheel may also be located behind the steering pivots. The primary purpose for this inclination is to give the vehicle a self-aligning characteristic and to prevent turns from being

self-sustaining. This imparts road "feel" to the steering wheel. This "feel" will be discussed later in this report. A second purpose is to align the dynamic forces acting on the vehicle under load and operation such that the alignment aids in the structural integrity. (See Figure 8.)

- Camber. The amount of lean that is designed into the steering road wheels is called "camber." Typically, the road wheels lean out at the top from the vehicle's vertical centerline. Camber causes turning and, of course, excessive opposite camber of both of the steered road wheels would introduce objectionable forces and wear. A slight amount of camber is built into the steering suspension system to compensate for operating wear and manufacturing tolerances to ensure that the steering suspension feels "tight" to the operator. (See Figure 9.)

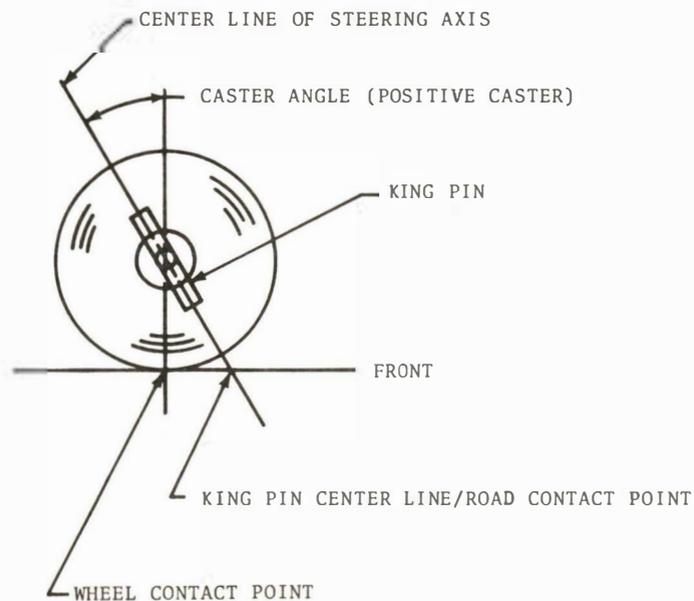


Figure 8. Caster

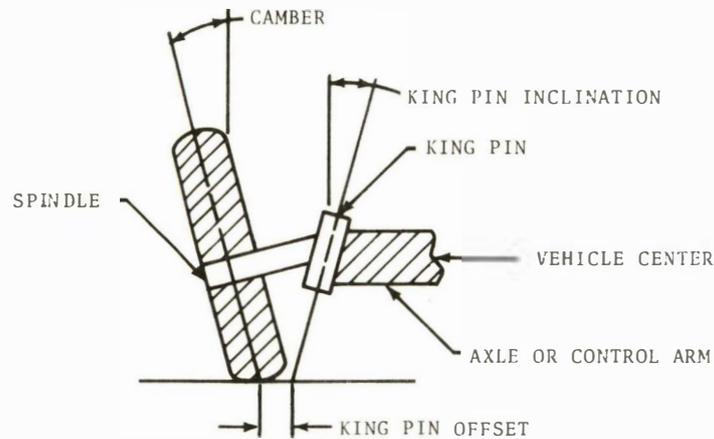


Figure 9. Camber, King Pin Inclination and King Pin Offset

- King Pin Inclination. King pin inclination is the inward tilt of the king pin from the vertical. This parameter has a strong affect on ease of steering and vehicle self-centering (return of wheels to a straight line when steering force is released). As the front wheels are turned around an inclined king pin, the vehicle frame is lifted. This lifting requires force and is experienced as a steering effort. When the steering effort is removed, a recovery force is experienced by the steering linkage. (See Figure 9.)
- King Pin Offset. The distance between the center of contact of the tire with the ground and the intersection of the king pin axis with the ground is called the king pin offset. If there is no such offset, the tires will tend to "scrub" around the center of road contact when turned in the static condition. Without this offset a high static steering effort is

required. However, if king pin offset is introduced, the tires will tend to roll around the intersection of the king pin axis with the ground, even though the turn is static. This results in a lower static steering effort requirement. King pin offset does increase the steering effort required while the vehicle is in motion. (See Figure 9.)

- Toe-In or Toe-Out. The distance between tire centerlines is typically slightly less at the front of the tire. This again is to compensate for wear and clearance in the steering linkage. Toe-in also compensates for the camber previously described. Toe-out is the opposite of toe-in and is a condition to be avoided. (See Figure 10.)
- Toe-Out During Turns. Toe-out on turns is the geometry by which the proper Ackerman geometry is achieved. This must be differentiated from the term "toe-out" just discussed. Toe-out during turns is a function of the steering linkage design.

These six parameters are combined into what is commonly called the vehicle steering geometry. This geometry is specifically designed to provide the steering characteristic desired in a particular vehicle. The configuration is usually unique for each vehicle model, and is influenced by the vehicle's intended use. These parameters are interdependent and when one parameter becomes changed due to wear or damage, it will change the overall system geometry with potential detrimental effects to the vehicle's steering performance. The correction of such conditions is commonly called realignment.

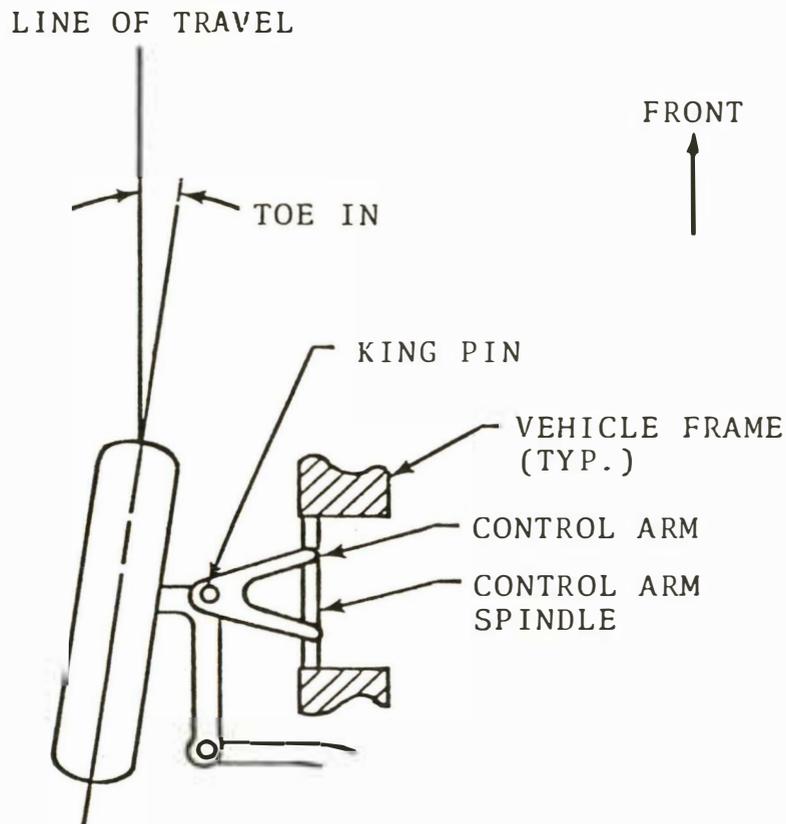


Figure 10. Toe-In

3.3 SYSTEMS APPROACH TO STEERING

The surface mining industry has and still is presenting unique steering system requirements for mining vehicles. Industry requirements for machines and vehicles to move increasing larger amounts of material at faster and yet safe rates has resulted in the development and application of steering system technology unique to these vehicles.

Steering system technology for the automobile and light truck industry is well defined and developed. Computer techniques for both design and dynamic modeling are highly developed. An excellent status of the automobile steering system design state-of-the art may be noted from the papers presented at the Second International Conference on Vehicle Structural

Mechanics. The integration of this automobile steering technology with hydraulic systems technology has resulted in the evolution of the steering systems used on many of today's surface mining vehicles.

The purpose of this section is to briefly describe the major results of this technology and the key components that are used in the various systems. For purposes of explanation, the key components are classified as either mechanical or hydraulic.

3.3.1 Mechanical Steering Elements

In their simplest form, steering systems are man powered. Man not only supplies the control, but also all the required power for turning the road wheels. The steering wheel in the vehicle cab is directly linked to the road wheels. Mechanical steering systems have undergone successive series of refinements as vehicle requirements have changed. Figure 11 shows a typical mechanical steering system.

Since vehicle speed and size have progressively increased, it has become necessary to introduce refined mechanical linkages between the road wheels and the operator to reduce the responsiveness and allow the operator to make larger steering wheel movements in relation to the movements of the road wheels and thereby reduce the tendency to "over-control" at these higher speeds. Also, as vehicle weight increased, the forces required to turn the road wheels increased and further "mechanical advantage" was required to reduce operator effort.

As both vehicle weight and performance continued to increase, man became the limiting factor. New steering system technology was required and steering system components with higher efficiencies had to be developed. Cam and lever steering drives with worm and roller gears were introduced to obtain



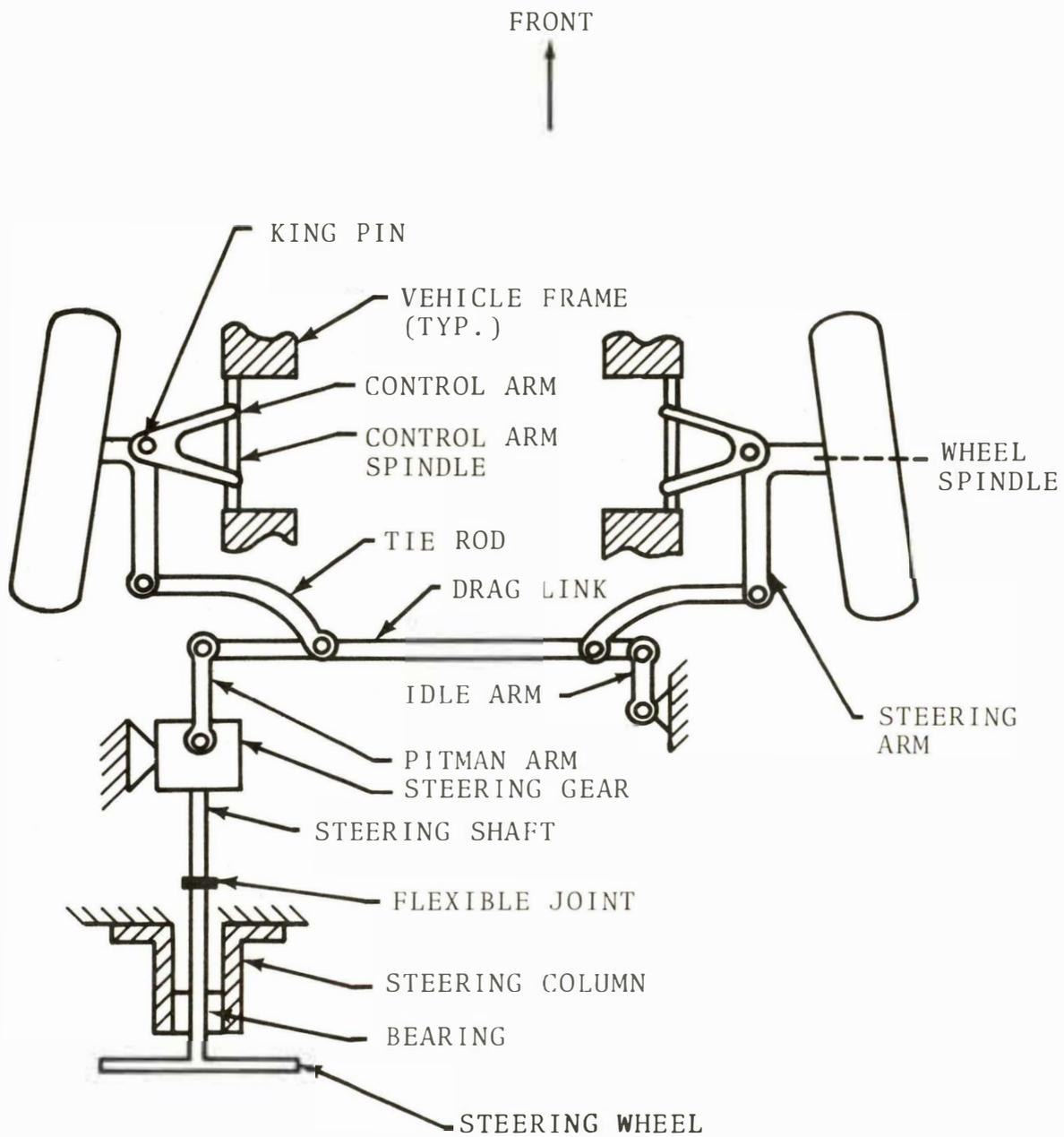


Figure 11. Typical Manual Steering System Linkage

these higher efficiencies by reducing steering system friction; to limit steering system play; and to better control the road shocks incurred by the road wheels. A typical worm and roller steering gear is shown in Figure 12.

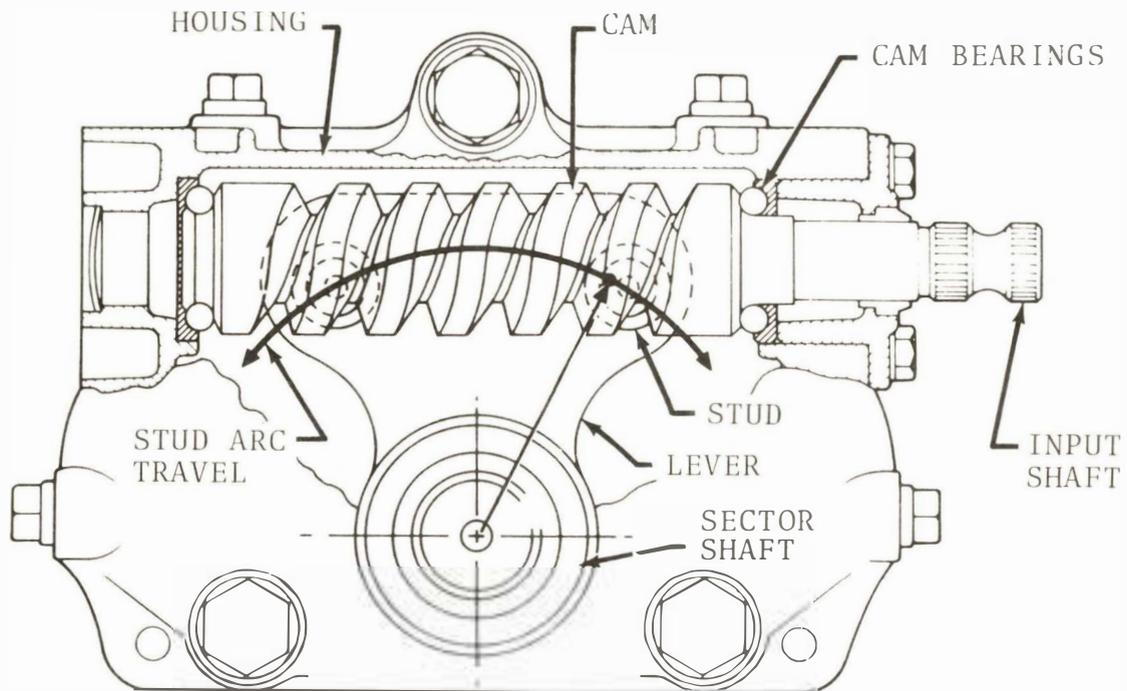


Figure 12. A Typical Worm and Roller Steering Gear

The ball screw drive was developed as the need for higher steering ratios became evident. The ball screw drive exhibits high efficiency in the reverse direction and prevents potentially high friction forces from limiting the action of the self-alignment characteristic incorporated in the steering geometry design. However, the high ratio still serves to limit the high road shock forces that could be transmitted to the steering wheel. A typical ball screw steering assembly is shown in Figure 13.

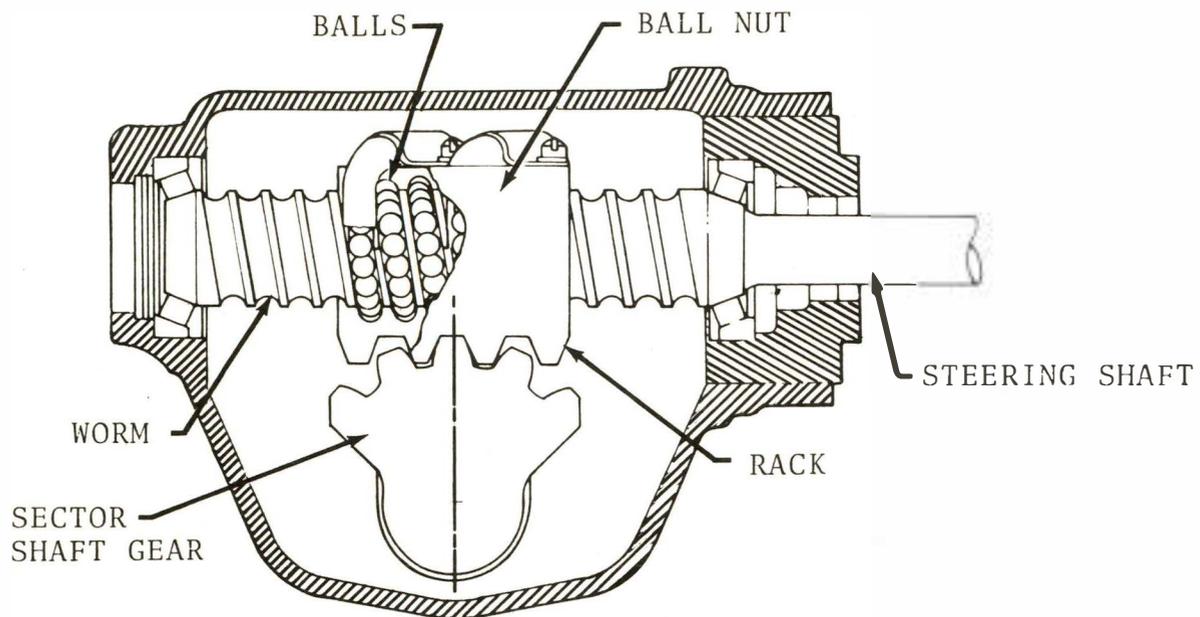


Figure 13. A Typical Ball Screw Gear Drive

3.3.2 Hydraulics Used in Steering Systems

Before entering into a discussion of power steering systems and hydraulic systems, a description of basic hydraulic components, their use and operation, terminology, and design symbols is in order.

Hydraulics (in the industrial sense) refers to the transmission of power utilizing incompressible fluids such as oil. (Pneumatics refers to the use of compressible fluids or gases such as nitrogen or air.) In a hydraulic system, it is possible to:

1. Convert rotary motion to linear motion without complex linkage,
2. Convert linear motion to rotary motion without complex linkage,
3. Regulate applied force,

4. Regulate speed of operations, and
5. Control and transmit power.

Hydraulics is attractive commercially because of system flexibility and ease of installation. System speed can be regulated using only a valve rather than a complex transmission and gear box; one power system (pump) may be used to power several actuators; system additions and modifications are easily made; and power density is high. A basic hydraulic system is a recirculating system consisting of these basic elements:

1. Reservoir (tank and the source of system fluid)
2. Pump
3. Relief valve
4. Valve (controller)
5. Actuator (cylinder or hydraulic motor)

A short description of each of these basic elements follows:

1. Reservoir. The reservoir is simply the system fluid storage tank.
2. Pump. There are two basic types of pumps:
 - a. Fixed Displacement Pump. The fixed displacement pump delivers a fixed volume of fluid for every revolution of the input shaft.
 - b. Variable Volume (Variable Displacement). The variable volume pump will deliver a variable volume of fluid (ranging from zero flow to maximum flow), at a given pressure, for every revolution of the input shaft. The volume delivered is controlled to meet the system requirements.



Ignoring losses the power consumed for the operation of a hydraulic system depends upon the quantity of oil, the pressure and the time. The horsepower input may be expressed as:

$$\text{hp} = \text{pressure} \times \text{flow} \times \text{constant}$$

where pressure = lb./in.²,

flow = gal./min.,

constant = 0.000583,

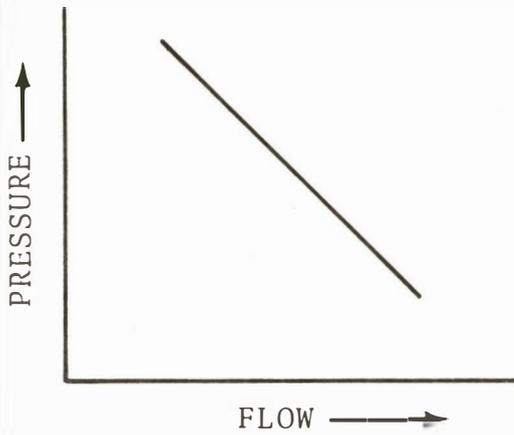
and hp = horsepower.

The actual input power necessary to produce this output is larger than this value because of friction losses.

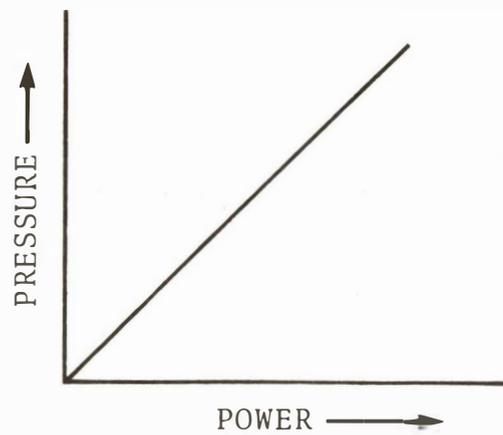
Figure 14 shows the relationships between power, flow rate, and pressure graphically.

The power input to the hydraulic system must be greater than the power required from the hydraulic actuators due to system losses. Typically, the designer calculates the rate of work required, chooses a system pressure based on the size and availability of components (cylinders), and then selects a pump to supply the required flow rate.

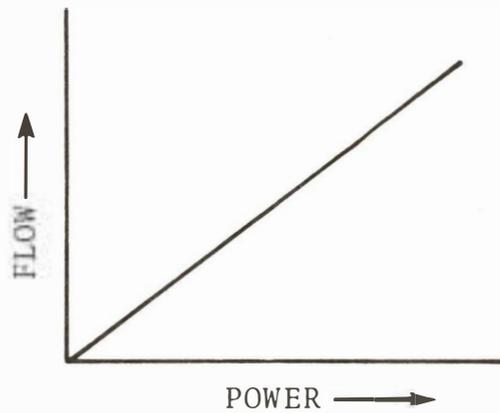
3. Relief Valve. The relief valve shunts the pump output back to the system reservoir when the pump output exceeds a preset pressure limit. This establishes the upper limit for system pressure and prevents overpressurization of the hydraulic system.



(A) CONSTANT INPUT POWER



(B) CONSTANT SPEED (CONSTANT VOLUME)



(C) CONSTANT PRESSURE

Figure 14. Relationships of Power, Pressure, and Flow Rate for Hydraulic Systems



4. Valves. The hydraulic valve performs three functions:
 - a. Starts or stops the flow,
 - b. Regulates the rate of flow, and/or
 - c. Directs the flow.

The hydraulic valve is the controller. With the valve, the equipment operator starts and stops an operation, changes the direction of an operation, or speeds up or slows down an operation.

5. Actuator. Hydraulic actuators are typically either hydraulic cylinders or hydraulic motors. A cylinder is sized by cylinder area and system pressure. The force available from a cylinder may be expressed as:

$$\text{Force (lb.)} = \text{pressure (psi)} \\ \times \text{area (sq. in.)}$$

If the rod end of the cylinder is to supply the force, the area is the cylinder area minus the area of the rod. The differential area of the cylinder and the rate of the stroke will determine the flow rate required. The direction of cylinder action is determined by the valve controlling it and to which end of the cylinder the flow is applied.

Hydraulic motors are sized based on torque requirements and horsepower.

A basic hydraulic system is shown schematically in Figure 15.

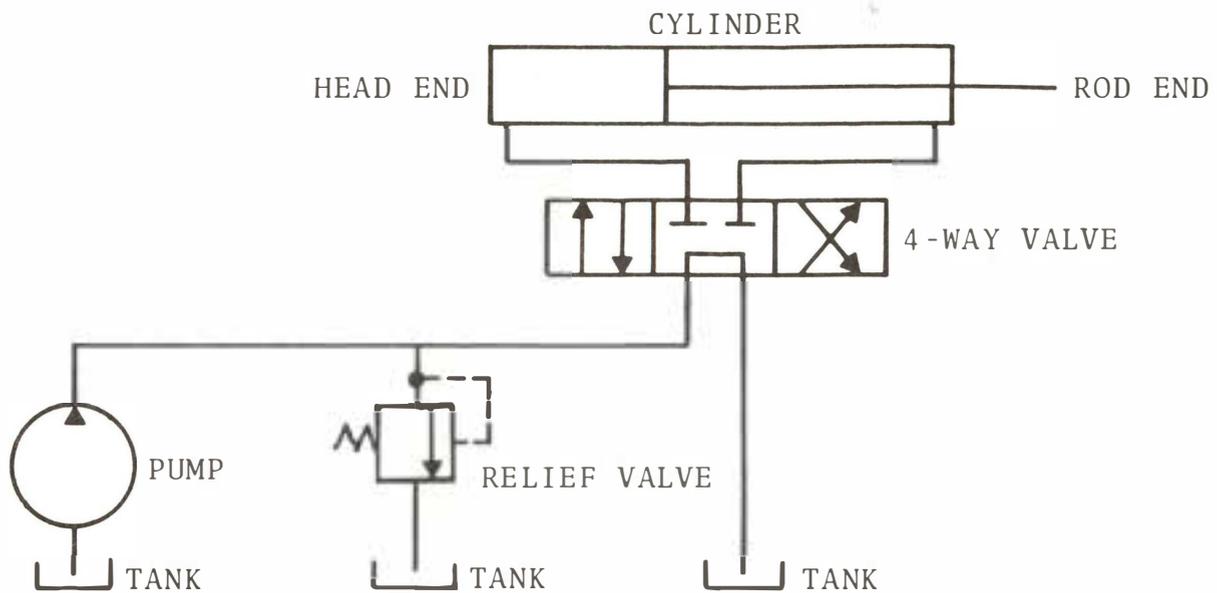


Figure 15. Basic Hydraulic System

The symbols used in the schematics are defined in Table 2 and individual components are described in detail.

Fluid (oil in the case of steering systems) is drawn from the reservoir, moved by the pump, and directed by the four-way valve to either the head end or rod end of the cylinder. The other end of the cylinder will automatically be connected back through the four-way valve to the reservoir (note the direction of the arrows). The system shown in Figure 15 uses an open center valve and a fixed displacement pump. The valve is shown in the neutral position. Both cylinder ports are blocked; the pressure port is connected to return the pump flow to the tank.

Most (but not all) four-way hydraulic valves used in surface mining equipment are spool type. As the name would imply, a sliding spool in the valve body connects ports in a

Table 2. Commonly Used Hydraulic Symbology



FIXED DISPLACEMENT
PUMP



CYLINDER



VARIABLE VOLUME
PUMP



GAS CHARGED
ACCUMULATOR



TANK



PRESSURE GAUGE



CHECK VALVE



4-WAY VALVE



HYDRAULIC LINE



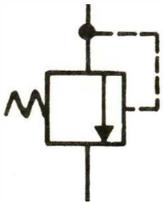
SHUT-OFF VALVE



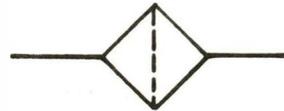
PILOT PRESSURE LINE



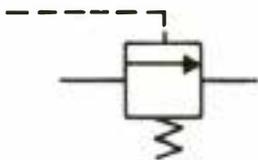
MOTOR



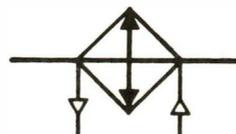
RELIEF VALVE



FILTER



PILOT OPERATED
UNLOADING VALVE



COOLER



different sequence depending on the direction of the spool movement. To effect operation, the spool may be shifted:

1. Manually,
2. By solenoid (electrically), or
3. By pilot operation (using either hydraulic or air pressure to move the spool).

Figures 16 and 17 show spool configuration in the neutral and shifted attitude. Figure 18 shows typical valve configurations using special spools.

Surface mining equipment typically uses hydraulic systems classified as "open center" or "closed center"; the nomenclature arising from the configuration of the valve when the spool is centered (in neutral). Basic examples of these configurations are shown in Figure 19.

The three spool valve-hydraulic system configurations illustrated in Figure 19 are described below.

Spool Valve-Hydraulic Systems

Open Center – Fixed Displacement Pump System (shown as (A) in Figure 19)

This is the simplest and most often used hydraulic system. When the four-way valve spool is centered, the output from the pump is returned directly to the tank (reservoir). Input power is only required to compensate for line flow losses. When the spool is shifted the pump is connected to the cylinder port; system pressure builds up; pressure builds up in the cylinder; and the cylinder is actuated. When the cylinder moves to a stop (motion ceases), the system pressure continues to build until the relief valve diverts pump flow to the sump or until the four-way valve is recentered. It should be noted that the relief valve must be set at some pressure higher than

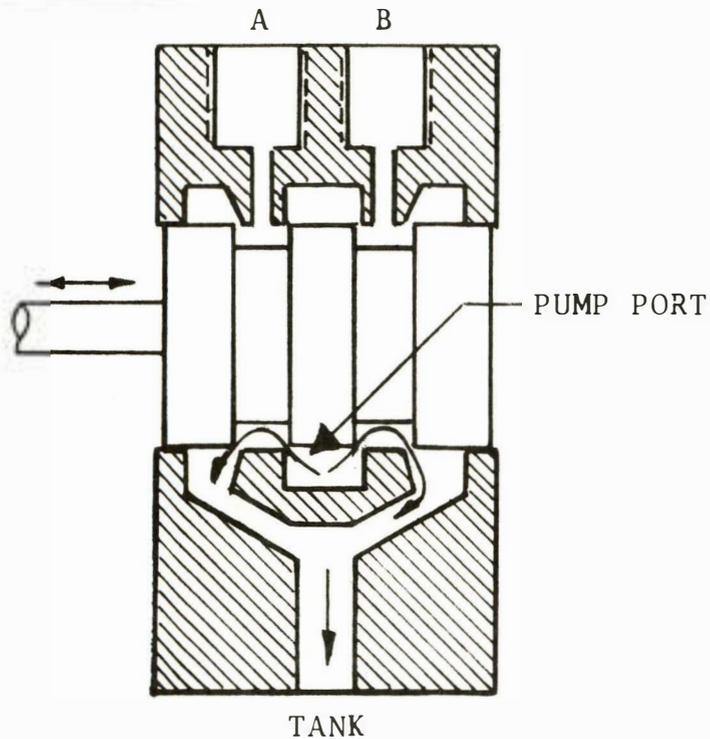


Figure 16. Typical Open Center Spool (with Open Cylinder Ports) Valve in Neutral Position

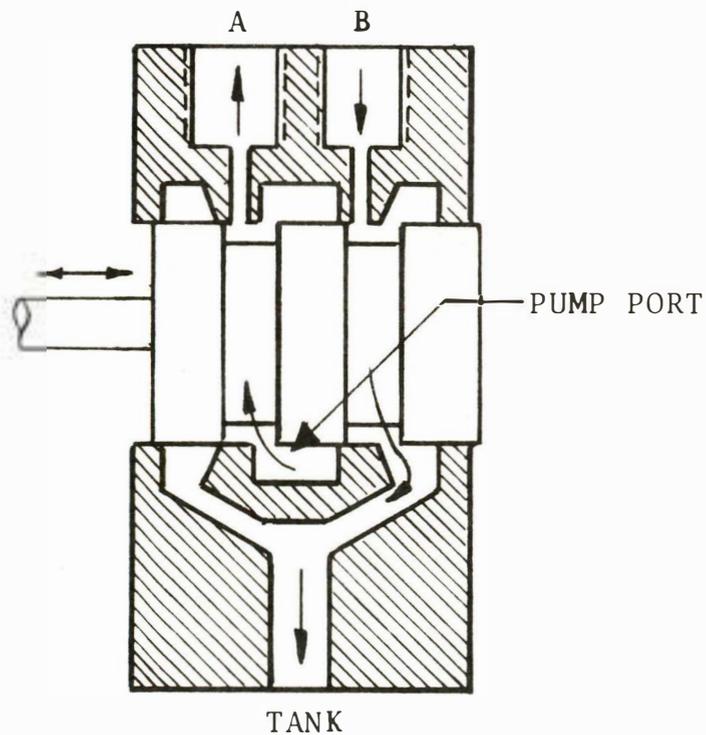
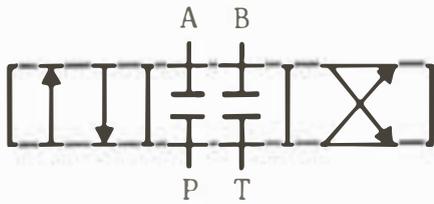


Figure 17. Same Spool Valve with the Spool Shifted to the Right - Pressure to Port A, Port B Returned to Tank



(A) CLOSED CENTER
CYLINDER PORTS
BLOCKED



(B) CLOSED CENTER
CYLINDER PORTS
CONNECTED



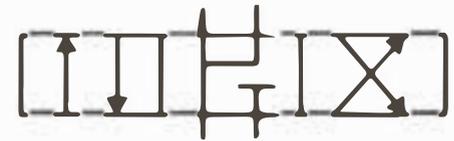
(C) OPEN CENTER
CYLINDER PORTS
BLOCKED



(D) OPEN CENTER
CYLINDER PORTS
CONNECTED



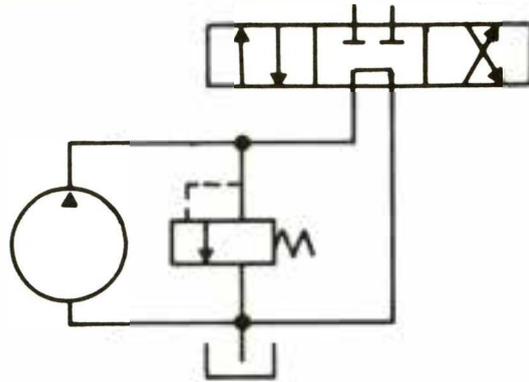
(E) CLOSED CENTER
CYLINDER PORTS
OPEN



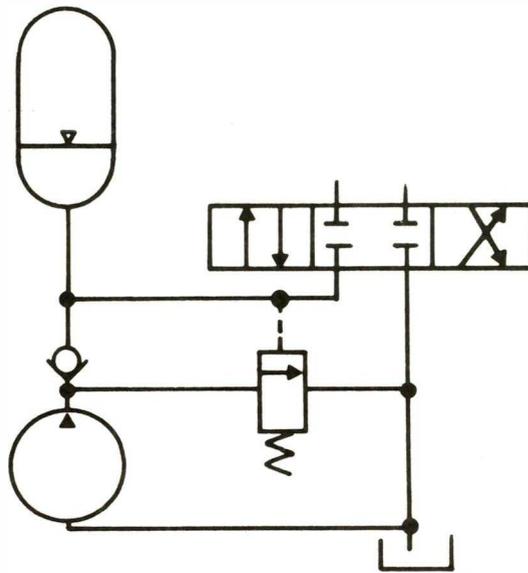
(F) OPEN CENTER
CYLINDER PORTS
PRESSURIZED

Figure 18. Typical Four-Way Valve Spool Configurations

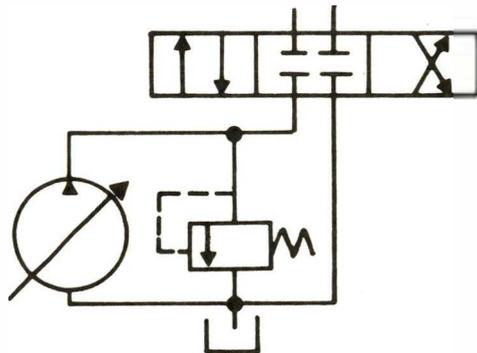




(A) OPEN CENTER-FIXED DISPLACEMENT PUMP



(B) CLOSED CENTER-FIXED DISPLACEMENT PUMP WITH UNLOADING VALVE



(C) CLOSED CENTER-VARIABLE VOLUME PUMP

Figure 19. Open and Closed Center Hydraulic Systems



the pressure usually required to move the cylinders or the cylinders would not be actuated. In some situations, when the cylinder motion stops, the fixed volume of oil being delivered by the pump drops from high pressure to low pressure across the relief valve. This is essentially wasted power and will be noted in the system as rejected heat and an increase in oil temperature. Figure 20 shows a typical operating cycle.

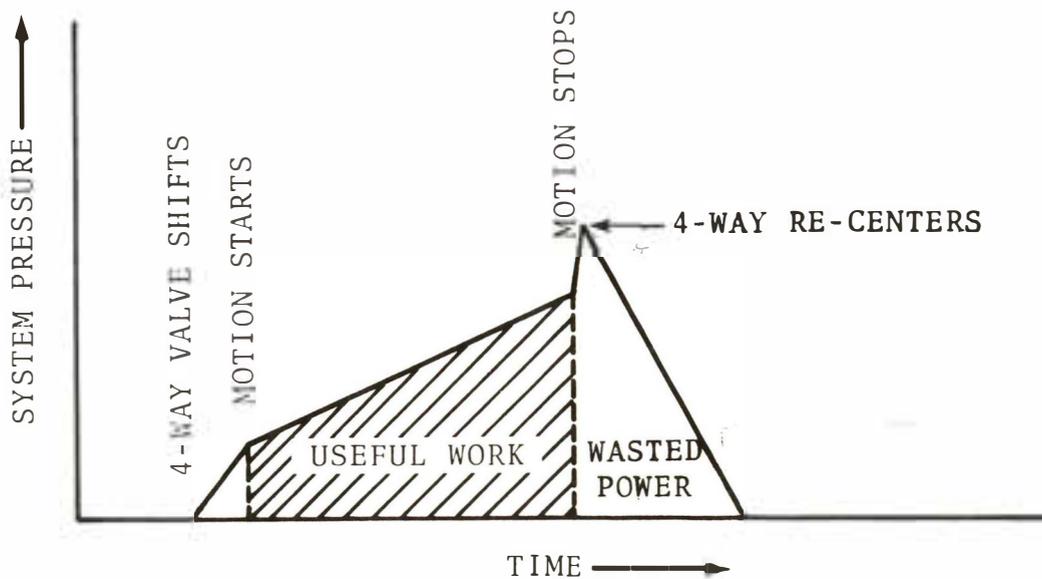


Figure 20. Typical Operating Cycle – Fixed Displacement Pump in an Open Center System



Closed Center – Fixed Displacement Pump with Unloading Valve (shown as (B) in Figure 19)

This configuration is also popular. In operation, the fixed displacement pump supplies oil to the system and charges up an accumulator (expansion chamber) to some upper pressure limit. At this upper pressure limit, the unloading valve actuates (opens) and diverts the pump flow back to the tank such that the pump pressure is reduced. At a selected lower system pressure, the unloading valve closes and the system pressure builds up again. The accumulator:

1. Stores energy in the form of pressurized hydraulic oil, and
2. May smooth the operating cycle.

The advantage of this system over (A) is that system operating pressure is available immediately when the four-way valve shifts and there is no need to wait for system pressure rise. This improves system response. It should be noted that there are still throttling losses introduced by the unloading valve since the accumulator output pressure is usually higher than the pressure required for steering. These systems require careful sizing of accumulator, pump, and unloading valve; require system "balancing"; and require careful analysis before modification to components or system operating characteristics. Figure 21 shows a typical operating cycle.

Closed Center with Variable Volume Pump (shown as (C) in Figure 19)

This configuration is considered by some designers to be one of the most energy efficient.

Operating pressure is available at the valve inlet port at all times. However, the output of the pump is essentially zero (since only leakage flow is required) except when flow is demanded (see Figure 22). Hence, waste power rejected to

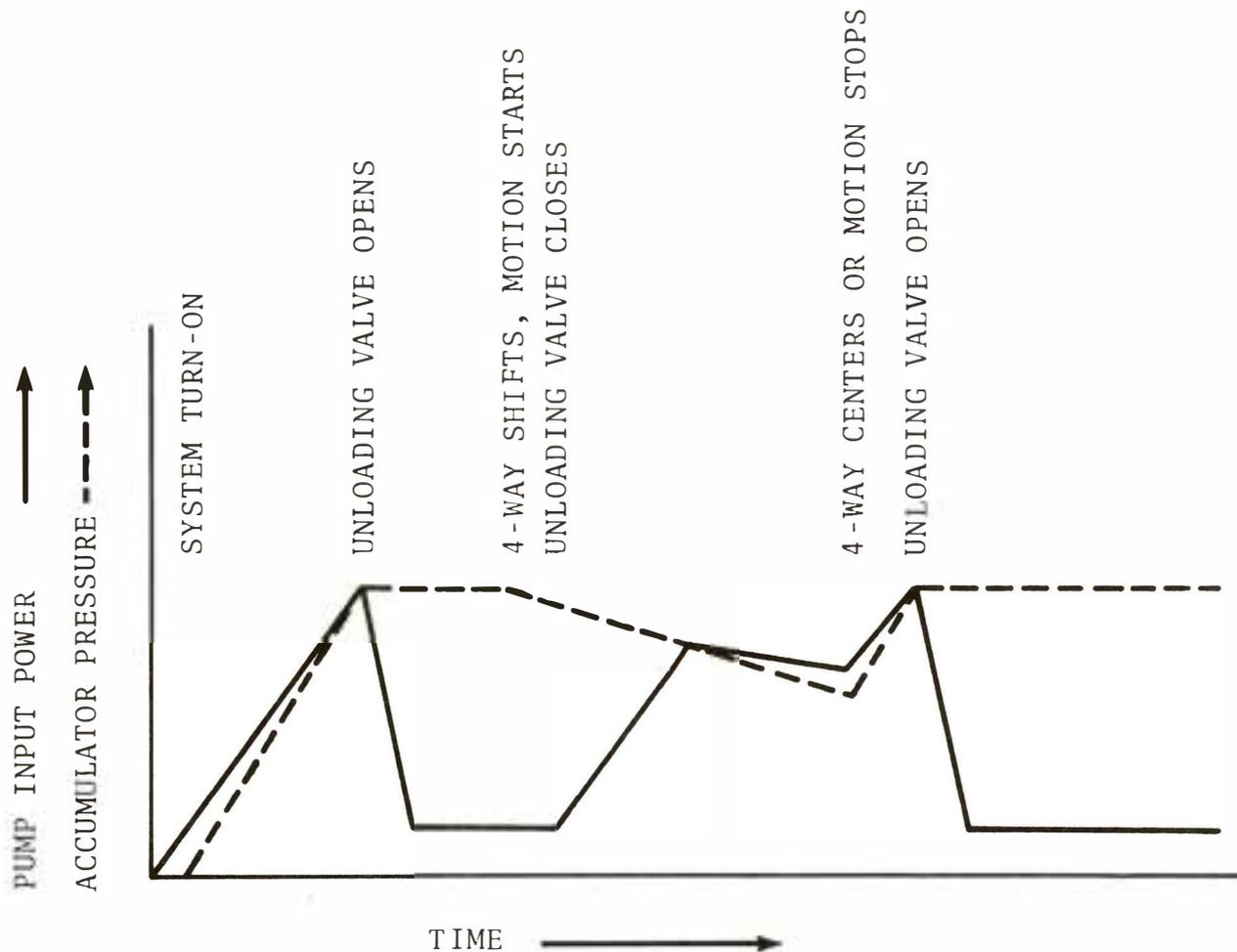


Figure 21. Typical Operating Cycle – Fixed Displacement Pump with Accumulator and Unloading Valve

the system is very low in the neutral valve mode. In operation, when the four-way valve spool shifts, the controller that establishes the pump flow rate senses a drop in system pressure and increases the volumetric output of the pump in such a manner as to supply sufficient flow to maintain the system pressure. When the volumetric demand ceases (cylinder motion stops or the four-way spool is recentered) the controller senses the rate of rise in system pressure and reduces the volumetric output of the pump accordingly. The flow rate again approaches zero with resulting elimination of almost



all hydraulic losses. This is a very basic description; in practice accumulators are sometimes included to smooth the cycle and supply surge demand and more elaborate control schemes are employed. Figure 22 shows a typical operating cycle of a closed center - variable volume pump system. Figure 23 shows the input power requirements of the closed center - variable volume pump system for the operating cycle shown in Figure 22.

Hydraulic Valves

Thus far, the discussion has covered four-way spool valves used principally for control and in an on-off mode. Other types of valves are commonly used in large equipment to perform specific functions. Common valve configurations are pictorially (schematically) described in Figure 24. It should be noted that combinations of these configurations may be used.

Accumulators

The hydraulic accumulator is a pre-charged expansion chamber. The pre-charge is usually a gas and is typically nitrogen introduced at a pre-charge pressure that is established as the lowest acceptable system operating pressure. The pre-charge may be contained in a bladder (bladder-type accumulator) or behind a piston (piston-type accumulator). The accumulator is sized to hold a specific volume of oil (an example would be five gallons) when the oil is introduced into the oil side of the accumulator at the maximum permissible system operating pressure. When the system pump is operating, the accumulator will be charged with oil. When a hydraulic valve is actuated, the accumulator and the pump will deliver oil to the system as long as this valve is actuated and there is demand (when a cylinder reaches its stroke limit, demand ceases). It must be noted that the accumulator can only deliver the volume of oil that it contains to the system. It

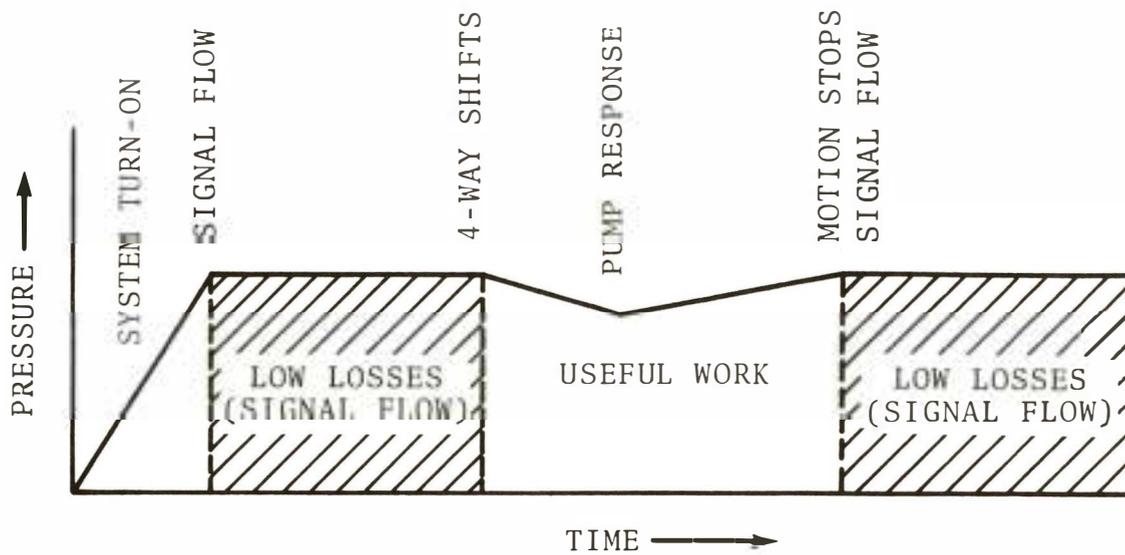


Figure 22. Typical Operating Cycle - Closed Center, Variable Volume Pump System

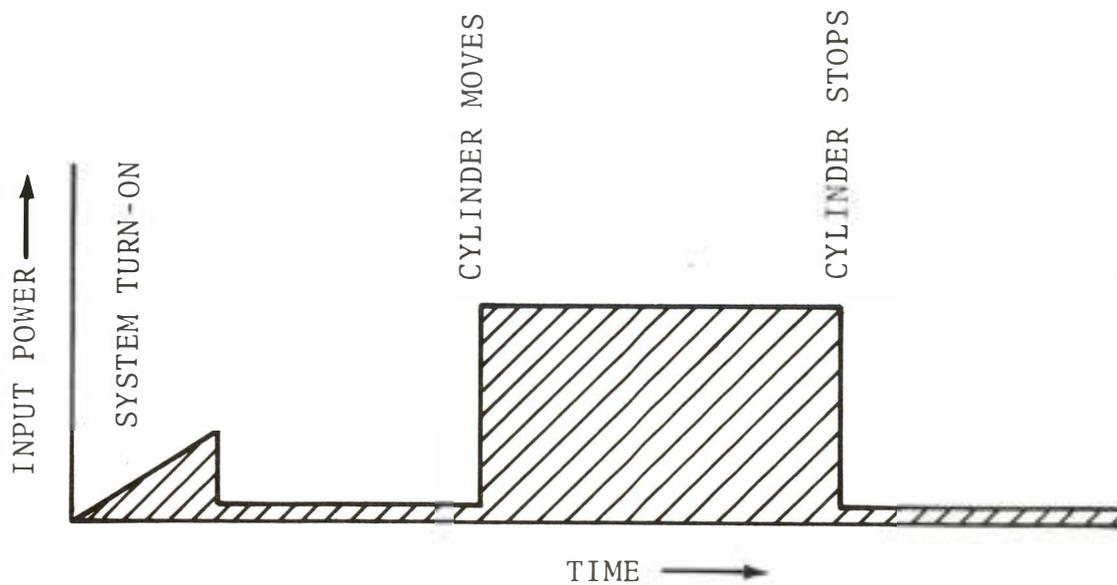
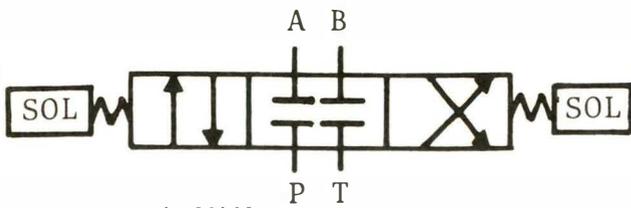


Figure 23. Input Power Requirements for Closed Center - Variable Volume Pump System



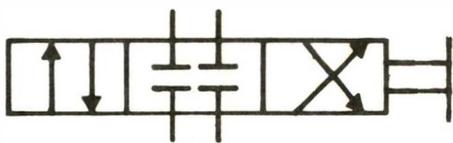
4-WAY
SOLENOID OPERATED
SPRING CENTERED

(A)



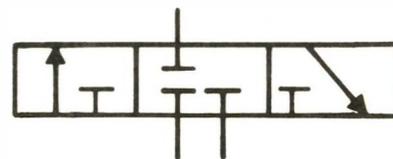
4-WAY
PILOT OPERATED
(USED HYDRAULIC PRESSURE)

(B)



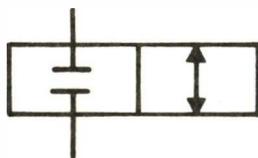
4-WAY
HAND OPERATED

(C)



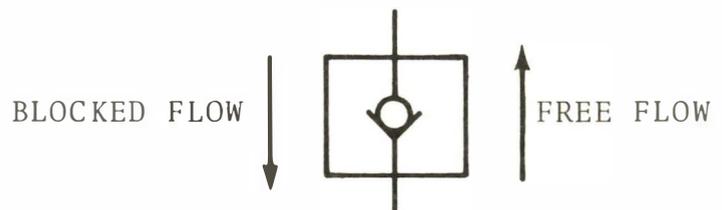
3-WAY
CLOSED CENTER

(D)



2-WAY

(E)



CHECK VALVE

(F)

Figure 24. Valves



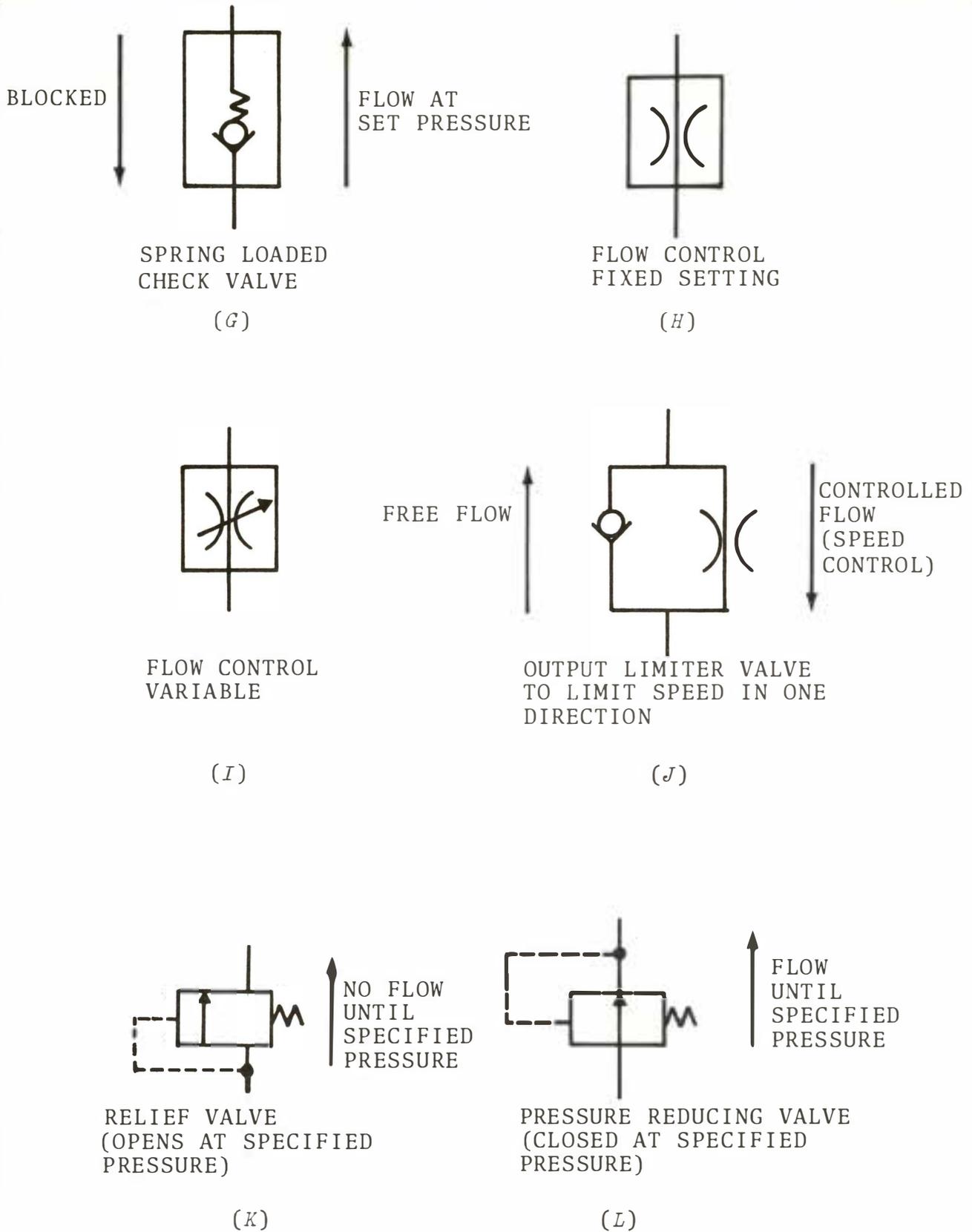


Figure 24. Valves (Cont)



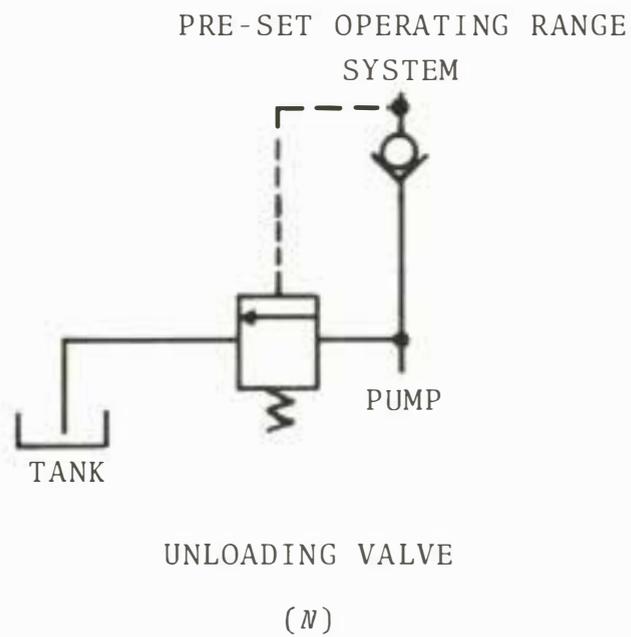
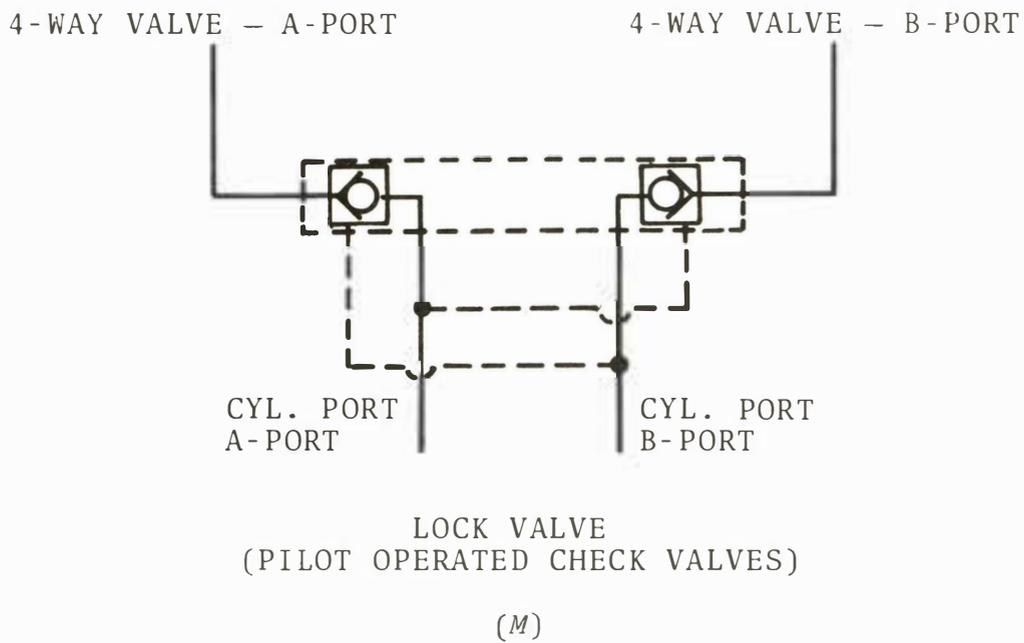


Figure 24. Valves (Cont)

will start oil delivery at the system pressure that exists at the moment of demand (if the system pressure is less than the maximum, then the volume available in the accumulator will be less than the maximum). The final available oil from the accumulator can only be delivered at the pre-charge pressure or system pressure, whichever is lower. Accumulators are used for smoothing the hydraulic cycle and as an emergency (auxiliary) fluid power source. Use of accumulators in closed-center systems may also allow the use of a smaller pump than would be necessary in the equivalent open-center systems. Figure 25 depicts the typical gas-charged/piston-type accumulator. Spring loaded accumulators are available but not commonly used.

Hydraulic System Schematics

The typical hydraulic system may be depicted by a schematic utilizing the previously described symbols. Figure 26 is a schematic of the typical closed center steering system incorporating a fixed displacement pump.

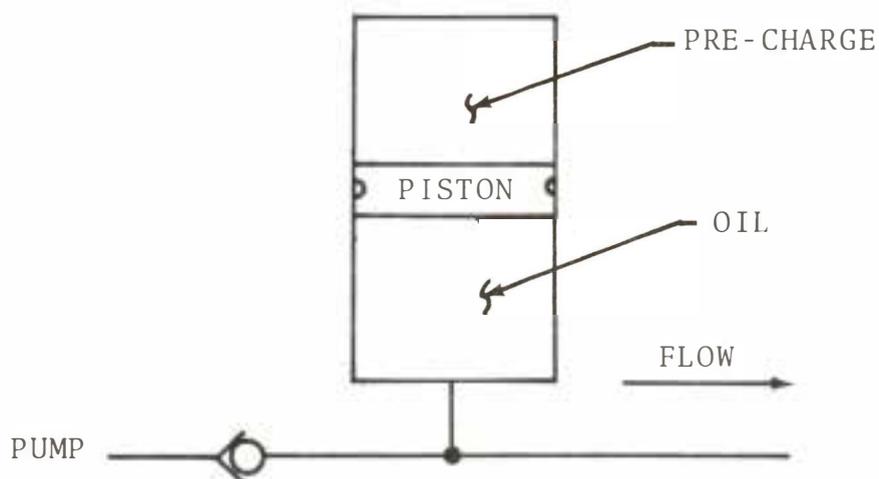
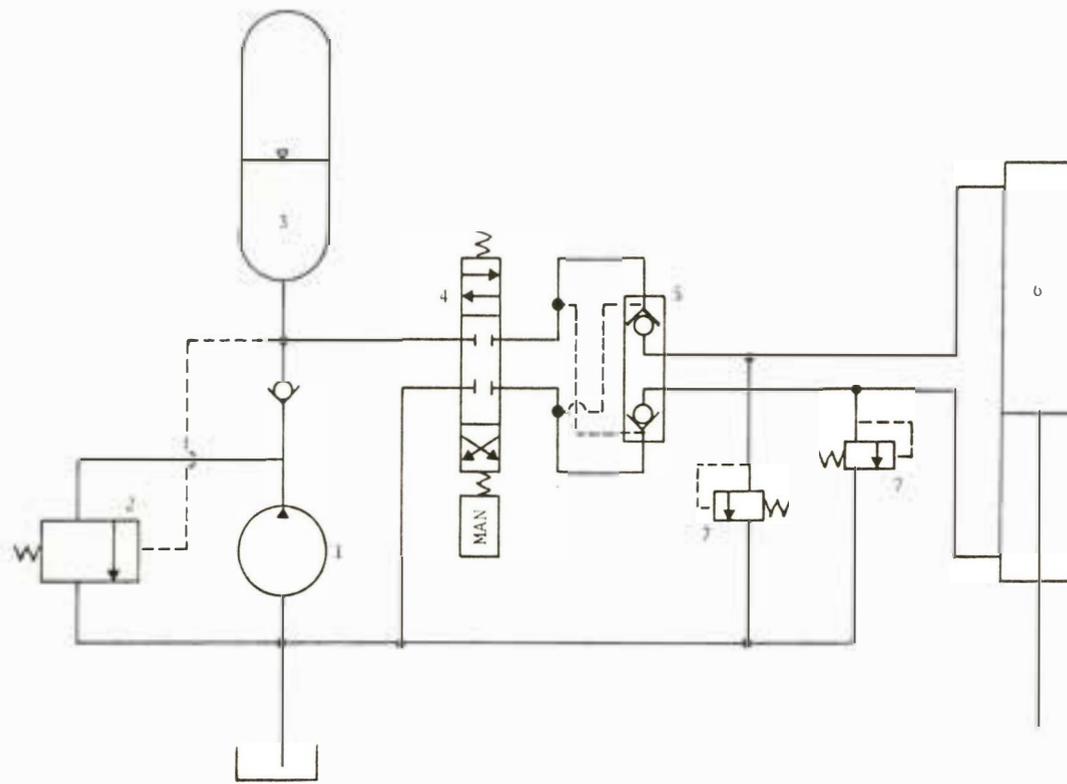


Figure 25. Piston-Type Accumulator



- (1) FIXED DISPLACEMENT PUMP
- (2) UNLOADING VALVE
- (3) ACCUMULATOR FOR NORMAL AND EMERGENCY SERVICE
- (4) CLOSED CENTER VALVE (SPRING CENTERED)
- (5) CYLINDER LOCK VALVE (PILOT OPERATED CHECK VALVES)
- (6) SINGLE ENDED HYDRAULIC CYLINDER
- (7) CYLINDER OVERPRESSURE RELIEF VALVES TO PREVENT OVER-PRESSURE OF HYDRAULIC SYSTEM FROM MECHANICAL SHOCK LOADS

Figure 26. Typical Closed Center Hydraulic Steering System Utilizing Fixed Displacement Pump

The cylinder lock valve is a combination of pilot operated check valves that keep the cylinder from "creeping" when the four-way valve is centered. Four-way valves typically have a certain amount of leakage around the spool. The overpressure relief valves relieve potentially destructive overpressure spikes introduced into the system from the cylinder when it is subjected to mechanical shock loads (road shocks).

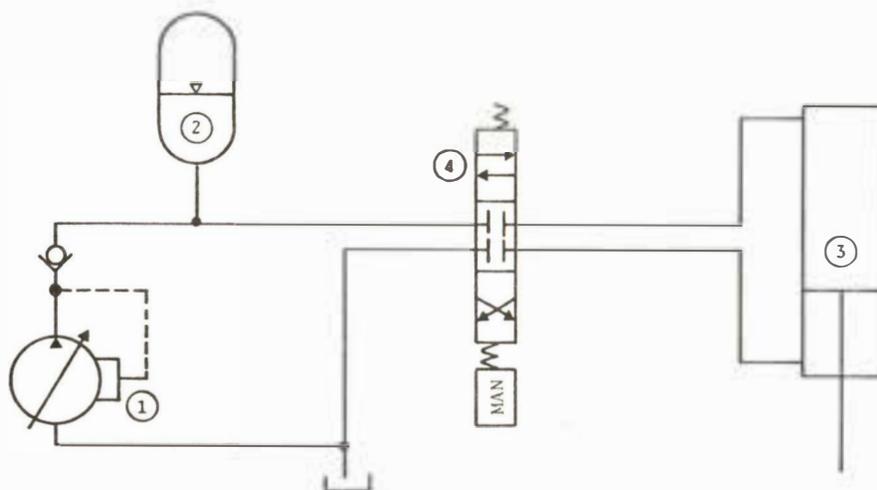
Figure 27 is a schematic of the typical closed center hydraulic steering system incorporating a variable volume pump. In this schematic, cylinder lock valves and cylinder over-pressure relief valves are not shown.

Figure 28 is a schematic of the typical open centered hydraulic system used on some surface mining equipment. Again, the lock valve and overpressure relief valves are not shown.

Control System Aspects

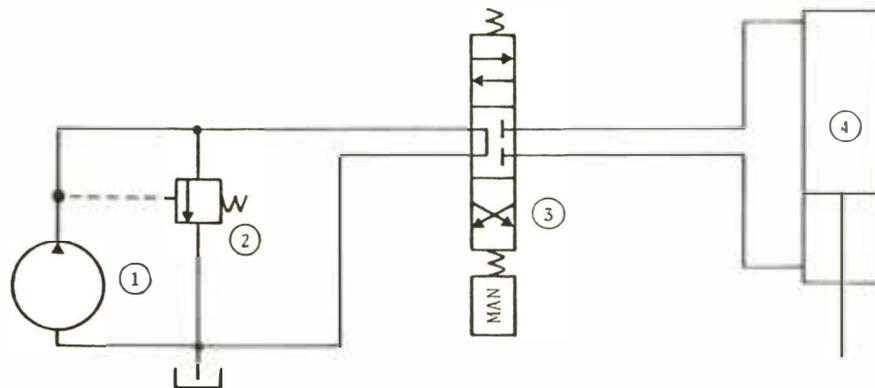
All steering systems are control systems. Power steering systems are a form of control system which may be called a:

1. Servomechanism,
2. Closed loop control system, and/or
3. Feedback control system.



- (1) PRESSURE COMPENSATED VARIABLE VOLUME PUMP
- (2) ACCUMULATOR FOR NORMAL AND EMERGENCY SERVICE
- (3) SINGLE ENDED HYDRAULIC CYLINDER
- (4) CLOSED CENTER VALVE

Figure 27. Typical Closed Center Hydraulic System Utilizing Variable Volume Pump



- (1) FIXED DISPLACEMENT PUMP
- (2) RELIEF VALVE
- (3) OPEN CENTER 4-WAY VALVE (SPRING CENTERED)
- (4) SINGLE ENDED HYDRAULIC CYLINDER

Figure 28. Typical Open Center Hydraulic System

To understand how a power steering system operates, one need only understand the basic principle of a servo-mechanical system. In such a system, there are two basic signals:

1. The command signal, and
2. The feedback (or error) signal.

The operator initiates a command signal that tells a driven element to drive to a certain point. The driven element sends back a feedback signal that indicates exactly how far it is from that point. The servo-system compares the command and feedback signals; supplies power to drive the driven element in the direction required to reduce the feedback (error) signal; and stops the action when the magnitude of the feedback signal reaches zero which indicates that the command signal has been satisfied. Command and error signals may be mechanical, electrical, or hydraulic.

The power steering system is the servo; it receives the command from the driver in the form of a precise amount

of turn of the hand steering wheel and actuates a hydraulic system that turns the road wheels the prescribed amount.

There are, of course, refinements of this concept (such as response time, rate of response, etc.) but these do not change the basic concept.

3.4 SURFACE MINING EQUIPMENT STEERING SYSTEMS

There are three basic steering system concepts employed on surface mining equipment. These are:

1. Mechanical,
2. Power assisted mechanical, and
3. Hydrostatic.

The mechanical and power assisted mechanical systems are only used on the smaller types of equipment; hydrostatic systems are used on almost all types of equipment with gross vehicle weights above 20,000-30,000 pounds.

3.4.1 Mechanical Steering Systems

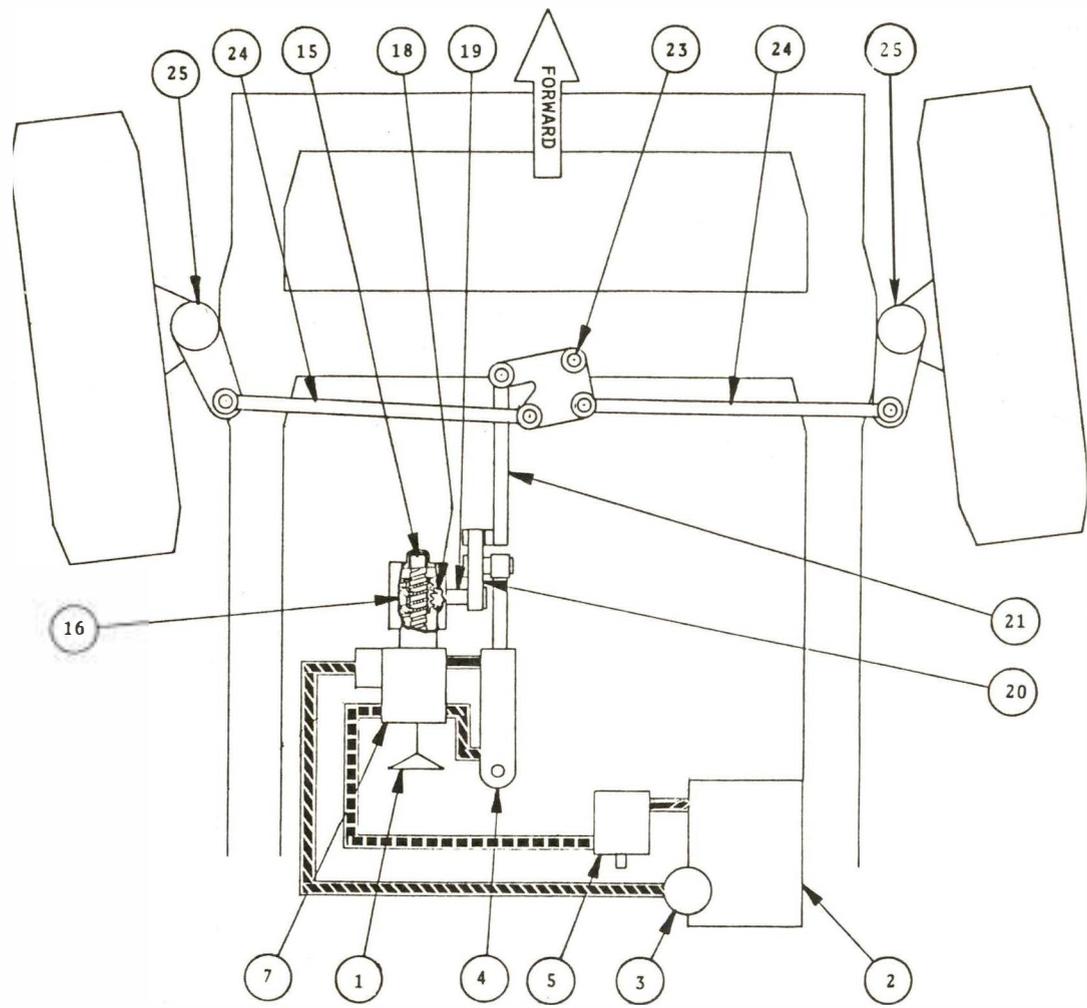
The principles of mechanical steering systems were discussed in the previous subsection (3.3.1). Due to the fact that the surface mining vehicle population using purely mechanical steering is very limited and because mechanical steering system technology is so well known and documented in numerous references, there will be no further discussion in this report.

The following two subsections will be concerned with power assisted mechanical systems and hydrostatic systems.

3.4.2 Power Assisted Mechanical Steering Systems

An open center power assisted mechanical steering system is shown in Figure 29. Power assisted mechanical steering





- | | |
|----------------------------|----------------------------|
| 1. STEERING WHEEL | 18. SECTOR GEAR |
| 2. HYDRAULIC OIL TANK | 19. SECTOR ARM |
| 3. FILTER | 20. PITMAN ARM |
| 4. STEERING CYLINDER | 21. DRAG LINK |
| 5. FIXED DISPLACEMENT PUMP | 23. BELLCRANK ARM ASSEMBLY |
| 7. STEERING CONTROL VALVE | 24. TIE ROD |
| 15. STEERING SHAFT | 25. KING PIN |
| 16. NUT, BALLSCREW TYPE | |
-
- | | |
|--------------------------------------------------------------------------------------|--------------------|
|  | SUPPLY |
|  | ACTUATING PRESSURE |
|  | RETURN |
|  | PUMP SUPPLY |

Figure 29. Power Assisted Mechanical Steering System – Open Center (Left Turn Mode)



systems operate in just the manner that the nomenclature indicates; the actual steering function is fully mechanical with power assistance (amplification) supplied to the operator by an integral hydraulic system. The operator is mechanically linked from the steering wheel to the road wheels. In the event of failure of the power assist system, the operator still has mechanical control of the steering function (of course the steering is much more difficult). In the description of the operations that follow, it is important that the sequence of operations and the relative movement between components be fully understood since this basic philosophy will hold true for the other systems that will be discussed. If one fully understands the "feedback" principles and the sequence of events, then it will be much easier to grasp the concepts involved in the fully hydrostatic steering systems. In this discussion, component nomenclature will be used rather than the element number shown in the schematic figure. There will, of course, be design variations found among components having the same nomenclature and these will be individually discussed in the descriptions of the various systems.

Power (hydraulic oil at the required pressure) for the power assisted system shown in Figure 29 is delivered by a fixed displacement hydraulic pump driven by the engine of the mining machine. This pump will usually be either a gear pump or a vane pump. The choice of pump is usually dependent on the design economics of the system and the specific application.

A control valve that will apply and direct the oil and control its pressure is integrated into the steering wheel shaft assembly. This control valve is a four-way hydraulic valve with the two ports that are connected to the steering cylinder blocked when the spool is in the neutral position (see Figure 18(C)). The spool of the control valve may incorporate linear motion (Figures 17 and 18) or may incorporate

rotary motion. In either case, the hydraulic function will be the same: pump flow (pressure) will be directed to either end of the steering cylinder depending upon the direction of turn desired. The spool of the four-way control valve is coupled directly to the steering wheel shaft and turning the steering wheel displaces the spool in the control valve body; turning the wheel in one direction displaces the spool in one specific direction and turning the steering wheel in the other direction displaces the spool in the opposite direction. The control valve body may be an integral part of the steering linkage and move in a set relationship with the road wheels. Thus, a common practice is to have the four-way hydraulic control valve spool directly linked to the steering wheel and the control valve body a part of the moving steering linkage.

When the steering wheel is turned, the control valve spool is displaced in the control valve body. Hydraulic oil at the required pressure is now directed through the control valve to one end of the steering cylinder. The steering cylinder is mounted between the machine frame and the steering linkage. In Figure 29, the rod end of the power steering cylinder is mounted to the pitman arm and the head end is pinned to the frame. The applied hydraulic pressure generates force causing the rod of the steering cylinder to move and hence to move the pitman arm. The control valve body is directly coupled to the pitman arm in such a manner that a specific movement of the pitman arm causes a specific movement of the control valve body. Turning the steering wheel has moved the control valve spool a specific distance; hydraulic fluid has been directed through the control valve to the steering cylinder moving the pitman arm and also the control valve body; and the control valve body is now moving relative to the control valve spool with the direction of movement so

chosen that the control valve body is seeking to locate itself over the spool in the neutral position, blocking the cylinder ports on the control valve, and hence stopping the flow of oil to the steering cylinder. This is the "feedback" or "servo" action previously discussed under Control System Aspects. Thus, a specific amount of steering wheel displacement has resulted in a specific amount of turning of the road wheels.

In practice, the linkage between the steering wheel and the control valve spool is generally accomplished through helical or torsion springs. This is done for two reasons:

1. To provide a means of valve actuation,
and
2. To impart a steering resistance or "feel"
to the system.

Incorporation of this spring loading feature allows the operator to exert a predetermined amount of steering force before the power steering "cuts in." The system is locked into a fully mechanical mode after some preset amount of movement of the control valve spool has been reached.

For purposes of explanation in the above discussion, the servo action of the steering system was followed through one complete operating cycle wherein a specific amount of steering wheel displacement resulted in a specific amount of road wheel turn. In actual operating practice, the operator will continue to turn the steering wheel and the control valve spool will continuously lead the control valve body until the operator ceases to turn the steering wheel. At that time the servo action will center the control valve spool within the control valve body. During any part of the steering operation, the operator is able to reverse the steering wheel or apply a steering correction while the servo action described above is occurring. This simply overrides the servo action; shifts



the control valve spool from one end of the control valve body to the other; reverses the direction of hydraulic flow; and reverses the direction of steer. Thus, the power assisted mechanical steering system works in a continual smooth mode. A properly designed system will exhibit all the "feel" and response of a simple mechanical drive linkage.

Steering speed or the rapidity with which steering corrections can be initiated is called steering response or steering system response. This response is a function of hydraulic flow determined by:

1. The hydraulic pump capacity,
2. The system pressure,
3. The power available to the pump,
4. The displacement of the steering cylinder(s),
and
5. The actuating devices (valves, etc.).

An open center hydraulic system provides the power assistance to the steering configuration shown in Figure 29. This type of hydraulic circuit is shown in Figure 30.

This is the most commonly used hydraulic system for power assisted mechanical steering systems. In this configuration, the fixed displacement pump continually supplies hydraulic oil to the control valve and the spool in the control valve is so configured that the oil is returned directly to the hydraulic reservoir while the spool is centered (in the neutral position). As previously noted in the discussions on hydraulic systems, this results in:

1. Little buildup of system pressure while the steering system is not in operation,

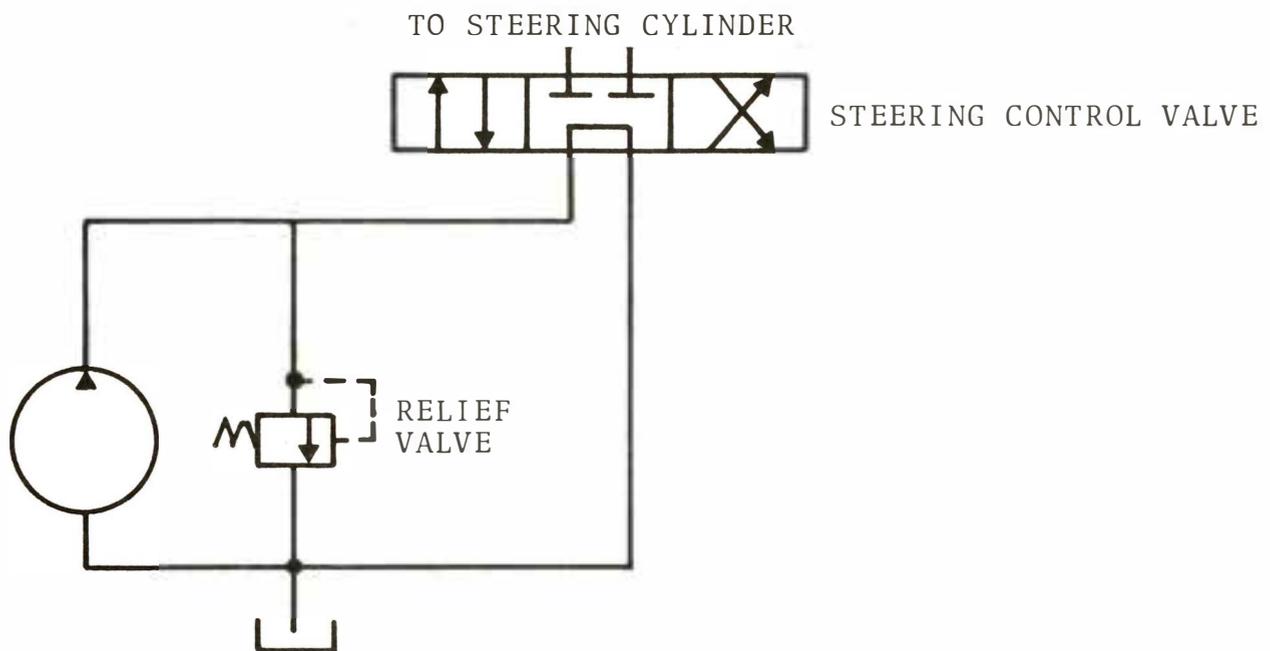


Figure 30. Hydraulic Circuit for Open Center – Fixed Displacement Pump System

2. Low power drain on the engine since the pump requires significant power from the engine only when supplying oil at high pressure,
3. Low heat buildup in the system since wasted power does not have to be dissipated through the hydraulic oil (except when the control valve spool is held shifted),
4. Hydraulic system simplicity and, usually,
5. Low system initial cost.

These attributes are mitigated to a small degree by sacrifice in system response since there must be system pressure buildup before each operating cycle. It should be noted that in a well designed system this delay is practically undetectable.

This power assisted mechanical steering system concept has found universal acceptance in the automobile. Many refinements to the system have come from the auto industry and have been incorporated into off-road machine development programs.

Power assisted mechanical steering systems, using open center spool valves, may be found on the following (and many other) machines:

- Caterpillar* 650B Twin Axled Tractor-Scraper
- Caterpillar 660B Twin Axled Tractor-Scraper
- Caterpillar 666B Twin Axled Tractor with Scraper Engine
- Fiat-Allis 100 Motor Grader

The closed center hydraulic configuration is also utilized in power assisted mechanical steering systems. The graphical description would be similar to Figure 29 and is not repeated. This variation requires the usage of the pump circuit shown in Figure 31 (with accumulator and unloading valve) and a steering control valve whose spool blocks hydraulic flow when in the neutral (centered) position. The variable volume pump circuit shown by Figure 32 is applicable but is not commonly used in the United States due to higher cost of the pump and possible contamination problems.

The closed center configuration is usually employed on machines wherein power steering hydraulic power and the hydraulic power for other machine functions can be supplied by a common pump, the common pump being selected because of cost or space constraints. Hydraulic system pressure (high pressure) is available at all times as is shown in Figure 33.

*Reference to specific brands, equipment, or trade names in this report is made to facilitate understanding and does not imply endorsement by the Bureau of Mines.

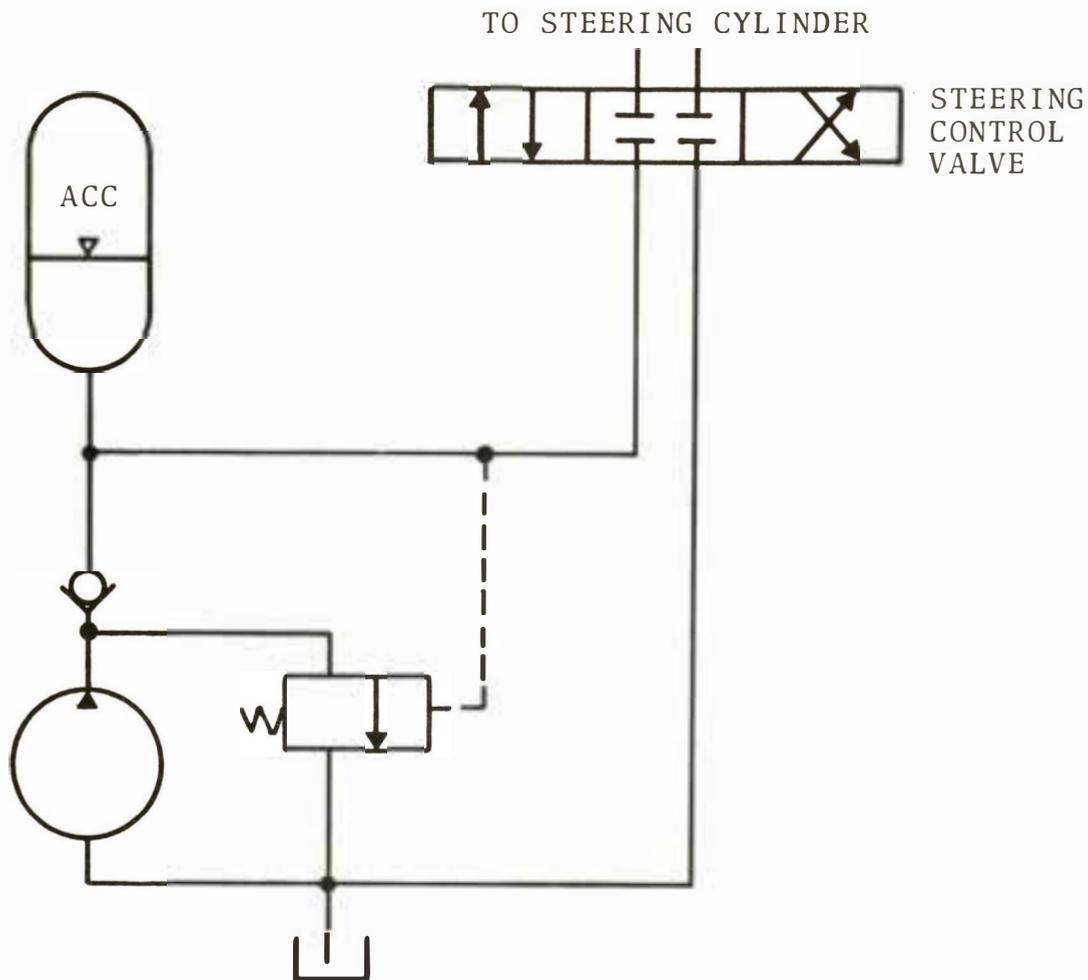


Figure 31. Hydraulic Circuit for Closed Center - Fixed Displacement Pump System

However, the advantage of having constant system pressure is mitigated by:

1. Additional system complexity,
2. Requirements for a hydraulic oil cooler since the wasted system power will be dissipated in the hydraulic oil and will result in heat buildup, and
3. More stringent maintenance requirements.

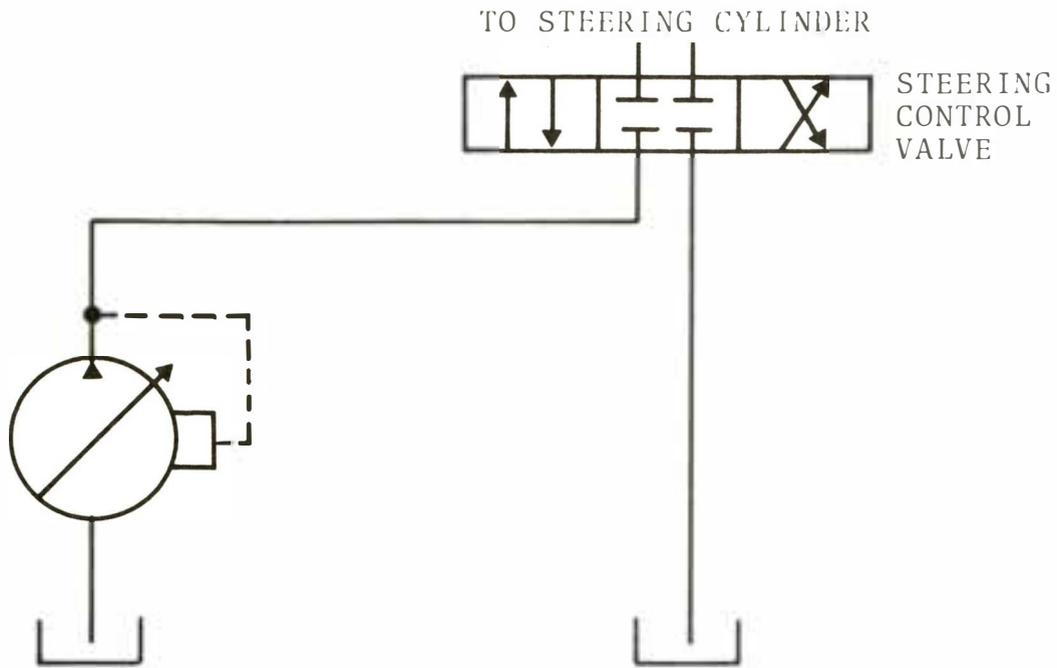


Figure 32. Hydraulic Circuit for Closed Center - Variable Volume Pump System

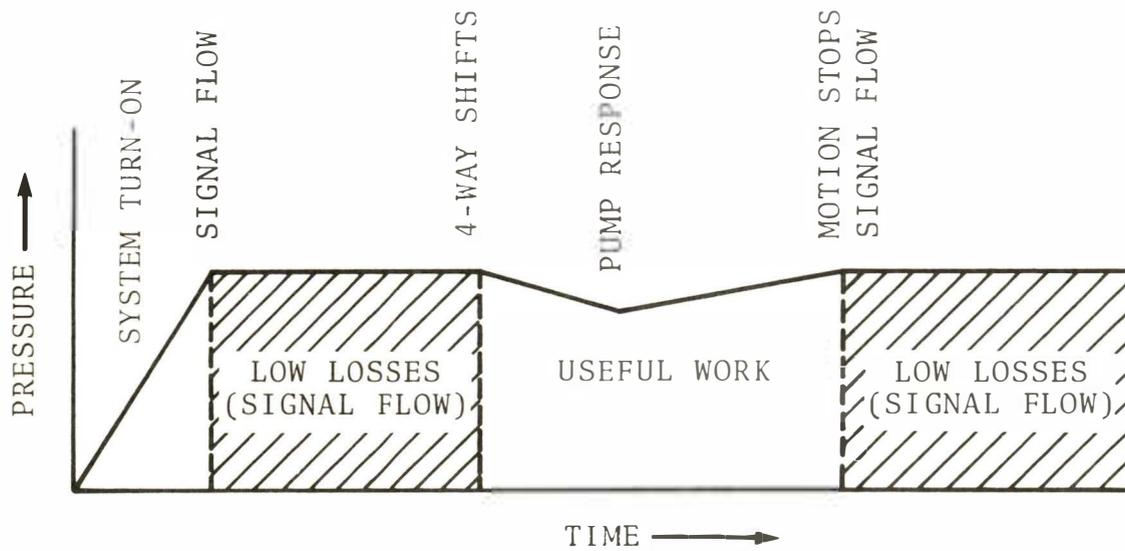


Figure 33. Typical Operating Cycle - Closed Center, Variable Volume Pump System

3.4.3 Hydrostatic Steering Systems

There are many variations to the basic hydrostatic steering system. Several of these variations and their key components are discussed in the following pages.

It should be noted that hydrostatic steering systems with mechanical feedback are almost identical in appearance to certain types of power assisted steering systems. The main difference is that in the event of a power source failure the machine cannot be steered to any appreciable degree by the operator through the use of the mechanical feedback mechanism.

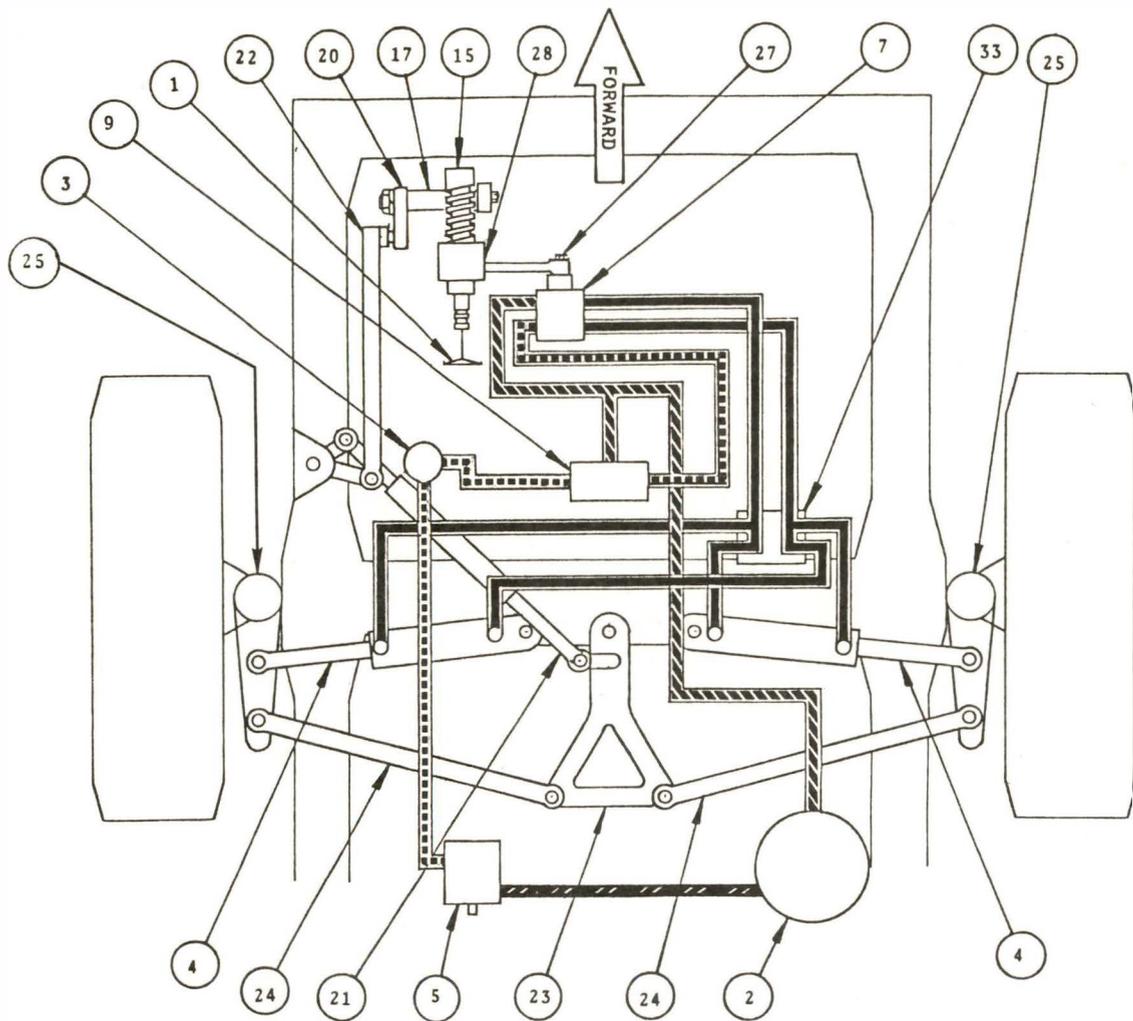
The hydrostatic steering system using an open center spool valve and employing mechanical feedback to the steering control valve is shown by Figures 34, 35, and 36. The operation of this system is almost identical to that of the power assisted mechanical steering system previously described except:

1. The system is fully dependent upon hydraulic power for operation, and
2. No mechanical steering capability is available in the event of hydraulic system failure in the steering system.

Figure 34 shows the hydraulic flow path when the steering control valve spool is in the neutral position (centered); Figure 35 shows the hydraulic flow path in a left turn mode; and Figure 36 shows the hydraulic flow path in a right turn mode. Two steering cylinders are shown since this is common design practice on larger vehicles that would utilize this system.

This system and the systems that will be subsequently discussed are typically used on large machines and there are certain characteristics that should be noted such as:

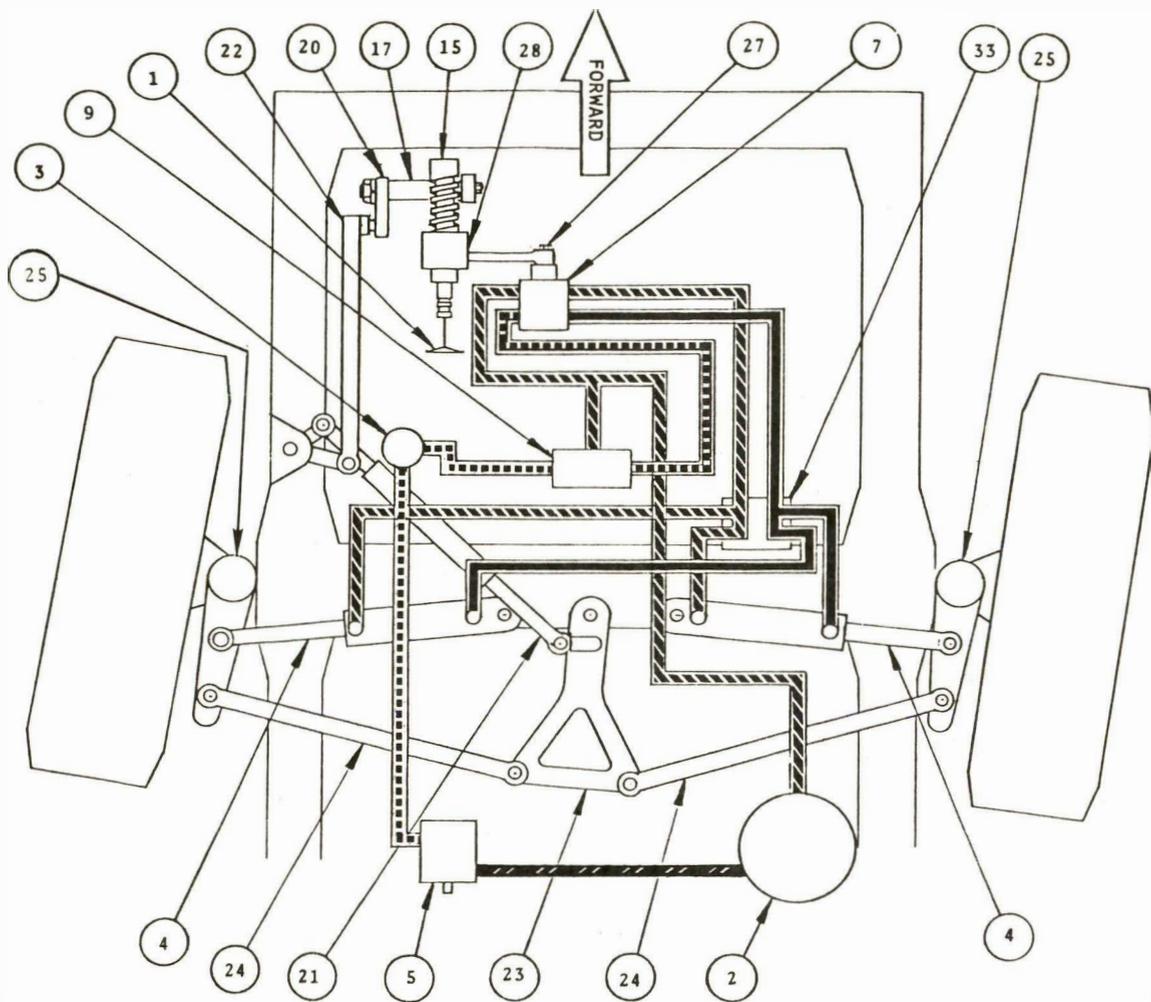
1. The only "feel" that the operator will experience at the steering wheel is that



- | | |
|----------------------------------|-------------------------------------|
| 1. STEERING WHEEL | 22. FEEDBACK LINK ASSEMBLY |
| 2. HYDRAULIC OIL TANK | 23. BELLCRANK ARM ASSEMBLY |
| 3. FILTER | 24. TIE ROD |
| 4. STEERING CYLINDER | 25. KING PIN |
| 5. FIXED DISPLACEMENT PUMP | 27. STEERING CONTROL VALVE SPOOL |
| 7. STEERING CONTROL VALVE | 28. STEERING CONTROL VALVE ACTUATOR |
| 9. FLOW CONTROL AND RELIEF VALVE | 33. MANIFOLD |
| 15. STEERING SHAFT | |
| 17. LEVER SHAFT AND STUD | SUPPLY |
| 20. PITMAN ARM | ———— ACTUATING PRESSURE |
| 21. DRAG LINK | - - - - - RETURN |
| | ▨▨▨▨ PUMP SUPPLY |

Figure 34. Hydrostatic Steering System with Mechanical Feedback to the Steering Control Valve Using an Open Center Spool Valve (Neutral Mode)





- | | |
|----------------------------------|---------------------------------------------------------------------------------------------------------|
| 1. STEERING WHEEL | 22. FEEDBACK LINK ASSEMBLY |
| 2. HYDRAULIC OIL TANK | 23. BELLCRANK ARM ASSEMBLY |
| 3. FILTER | 24. TIE ROD |
| 4. STEERING CYLINDER | 25. KING PIN |
| 5. FIXED DISPLACEMENT PUMP | 27. STEERING CONTROL VALVE SPOOL |
| 7. STEERING CONTROL VALVE | 28. STEERING CONTROL VALVE ACTUATOR |
| 9. FLOW CONTROL AND RELIEF VALVE | 33. MANIFOLD |
| 15. STEERING SHAFT | |
| 17. LEVER SHAFT AND STUD |  SUPPLY |
| 20. PITMAN ARM |  ACTUATING PRESSURE |
| 21. DRAG LINK |  RETURN |
| |  PUMP SUPPLY |

Figure 36. Hydrostatic Steering System with Mechanical Feedback to the Steering Control Valve Using an Open Center Spool Valve (Right Turn Mode)

"feel" that is built into the steering control valve by the addition of friction to simulate steering resistance,

2. The transmission of road shocks to the steering wheel is reduced,
3. Steering system response is totally dependent on the hydraulic flow rate and this flow rate may be low at low pump speeds giving sluggish response, and
4. Vehicle self-correction from a turn may not be incorporated into the steering geometry.

These comments will be discussed in greater detail later in this report.

It should be noted that the hydrostatic steering system shown in Figures 34, 35, and 36 does not incorporate an emergency or auxiliary source of hydraulic power. Therefore, in the event of engine failure, the steering system would become immediately inoperative since the system is not designed to be operated through the mechanical feedback linkage. Emergency and auxiliary hydraulic power sources will be discussed later in this report.

Hydrostatic steering systems using an open center spool valve and employing mechanical feedback are found on many mining vehicles including the following equipment models:

- Caterpillar 769B Rear Dump Truck
- Caterpillar 772 Prime Mover
- Caterpillar 773 Rear Dump Truck
- WABCO 85C Haulpak Rear Dump Truck
- Euclid R-50 Rear Dump Truck

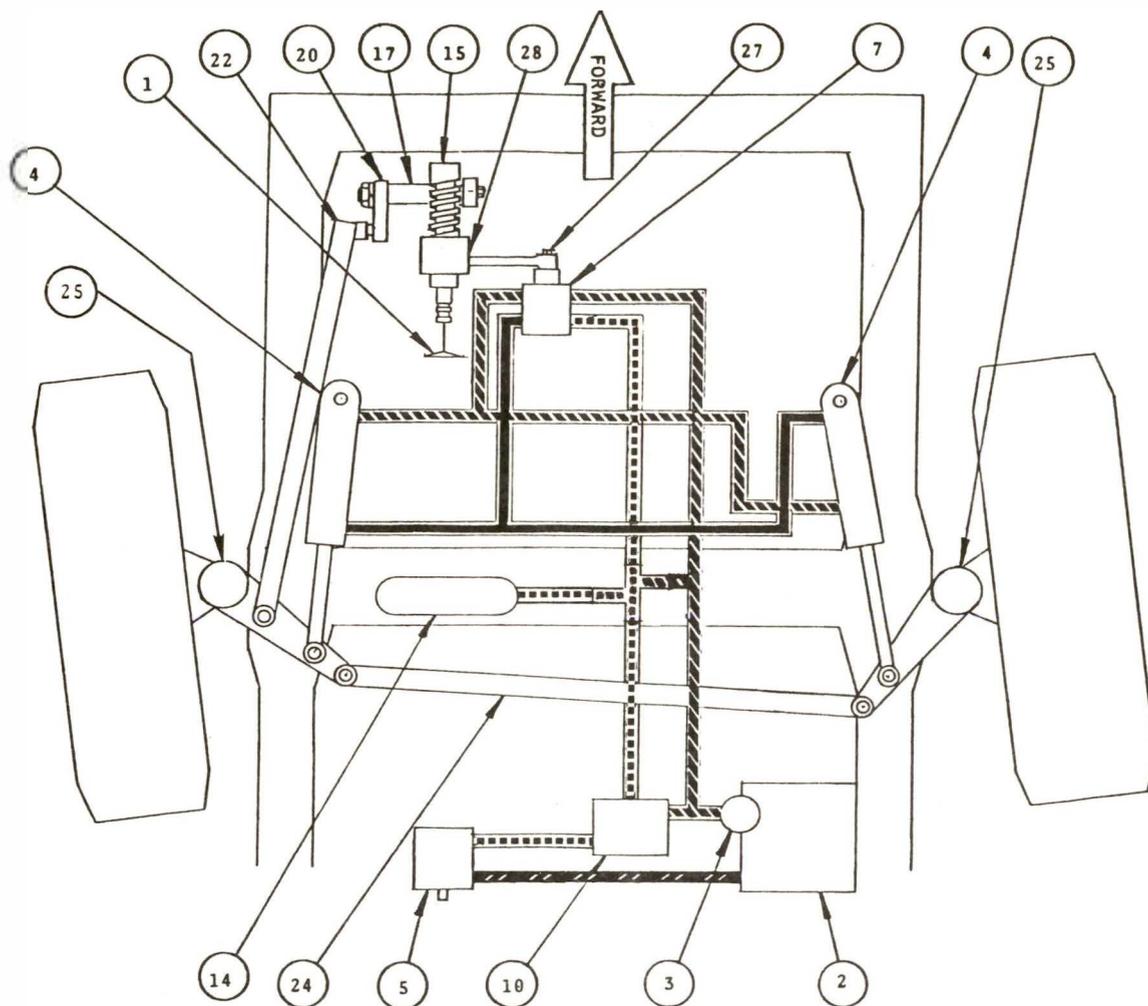
Figure 37 shows a hydrostatic steering system using a closed center spool valve and employing mechanical feedback to the steering control valve. The operation of this system is identical to that of the open center version shown in Figures 34, 35, and 36 except:

1. System pressure is always present at the steering control valve,
2. System response may be somewhat faster since operating pressure does not have to build up, and
3. The accumulator will continue to supply hydraulic power in the event of an engine failure until the volume of oil stored in the accumulator is exhausted by steering system actuation. At that point, steering capability will cease since the system is not designed to operate through the mechanical feedback linkage.

The closed center configuration requires the use of the pump circuit shown in Figure 31. A hydraulic oil cooler may or may not be required with this system, depending upon system size and the amount of heat that is actually generated in the oil. The variable volume pump circuit shown in Figure 32 is also applicable and is in limited use in the United States.

Hydrostatic steering systems using a closed center spool valve and employing mechanical feedback are found on the following representative equipment models:

- WABCO 120C Electric Haulpak Truck
- WABCO 150CW Electric Haulpak Truck



- | | |
|----------------------------|-------------------------------------|
| 1. STEERING WHEEL | 17. LEVER SHAFT AND STUD |
| 2. HYDRAULIC OIL TANK | 20. PITMAN ARM |
| 3. FILTER | 22. FEEDBACK LINK ASSEMBLY |
| 4. STEERING CYLINDER | 24. TIE ROD |
| 5. FIXED DISPLACEMENT PUMP | 25. KING PIN |
| 7. STEERING CONTROL VALVE | 27. STEERING CONTROL VALVE SPOOL |
| 10. UNLOADING VALVE | 28. STEERING CONTROL VALVE ACTUATOR |
| 14. ACCUMULATOR | |
| 15. STEERING SHAFT | |
- [Dotted Line] SUPPLY
 [Solid Line] ACTUATING PRESSURE
 [Hatched Line] RETURN
 [Hatched Line] PUMP SUPPLY

Figure 37. Hydrostatic Steering System with Mechanical Feedback to the Steering Control Valve Using a Closed Center Spool Valve (Left Turn Mode)

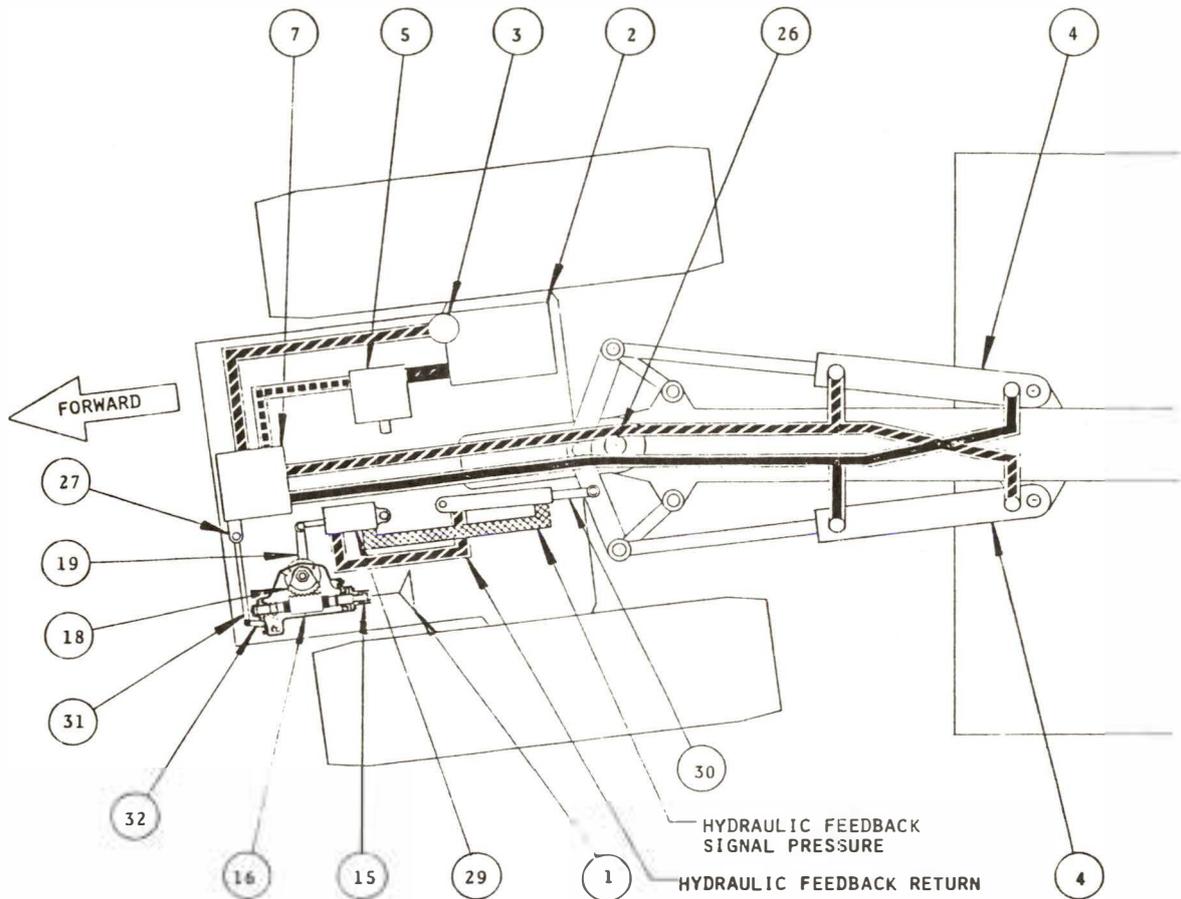


- WABCO 170C Electric Haulpak Truck
- Terex 72-21A, 72-31A, 72-41A, and 72-51A Loaders

Figure 38 shows a hydrostatic steering system using an open center spool valve with hydromechanical feedback to the steering control valve. This system is used almost exclusively on articulated vehicles. It is important to note that the position of the spool within the steering control valve is controlled by a servo-mechanical linkage which is positioned by hydraulic feedback. All the relative motions for the servo movements are accomplished within the servo-mechanical linkage. Figure 39 shows the construction of the servo-mechanical linkage and describes the series of operations that occur during a specific steering operation. Only an incremental steering operation has been described. Continuous steering can be effected as has been described in the other systems.

Hydrostatic steering systems using closed center spool valves with hydromechanical feedback to the steering control valve are feasible but are not in common usage in the United States. The hydraulic circuits for the pumps would be similar to those shown in Figures 31 and 32.

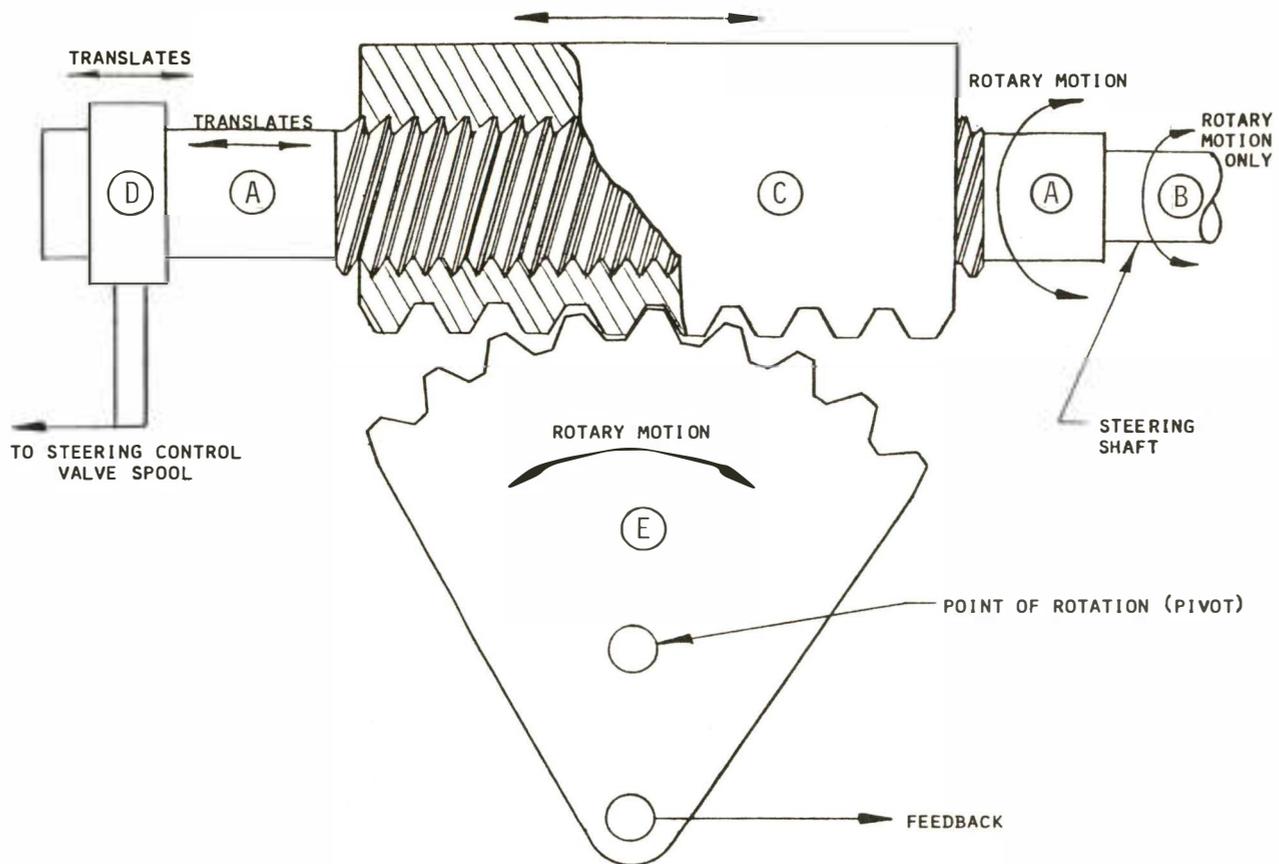
Hydrostatic steering systems without feedback and utilizing hand metering pump/valves are shown in Figures 40 and 41. These pump/valves or devices are sold under various trade names each having individual features. This type device is actuated by rotary motion from the steering wheel and each rotation of the input shaft delivers a precise volume of hydraulic oil to the steering cylinders. Since the hydraulic oil is incompressible, each turn of the input shift (steering wheel) will result in a specific displacement of the steering cylinders. The hand metering pump/valve also incorporates a spool action so that it may operate in either an open center



- | | |
|----------------------------|-----------------------------------------------------------------------------------|
| 1. STEERING WHEEL | 26. ARTICULATION POINT |
| 2. HYDRAULIC OIL TANK | 27. STEERING CONTROL VALVE SPOOL |
| 3. FILTER | 29. STEERING VALVE SPOOL CONTROL CYLINDER |
| 4. STEERING CYLINDER | 30. FEEDBACK CYLINDER |
| 5. FIXED DISPLACEMENT PUMP | 31. CONTROL VALVE SPOOL LINKAGE |
| 7. STEERING CONTROL VALVE | 32. LEVER |
| 15. STEERING SHAFT | |
| 16. NUT, GEAR | |
| 18. SECTOR GEAR | |
| 19. SECTOR ARM | |
| | SUPPLY
ACTUATING PRESSURE
RETURN
FEEDBACK SIGNAL PRESSURE
PUMP SUPPLY |

Figure 38. Hydrostatic Steering System with Hydromechanical Feedback to the Steering Control Valve Using an Open Center Spool Valve (Left Turn Mode)

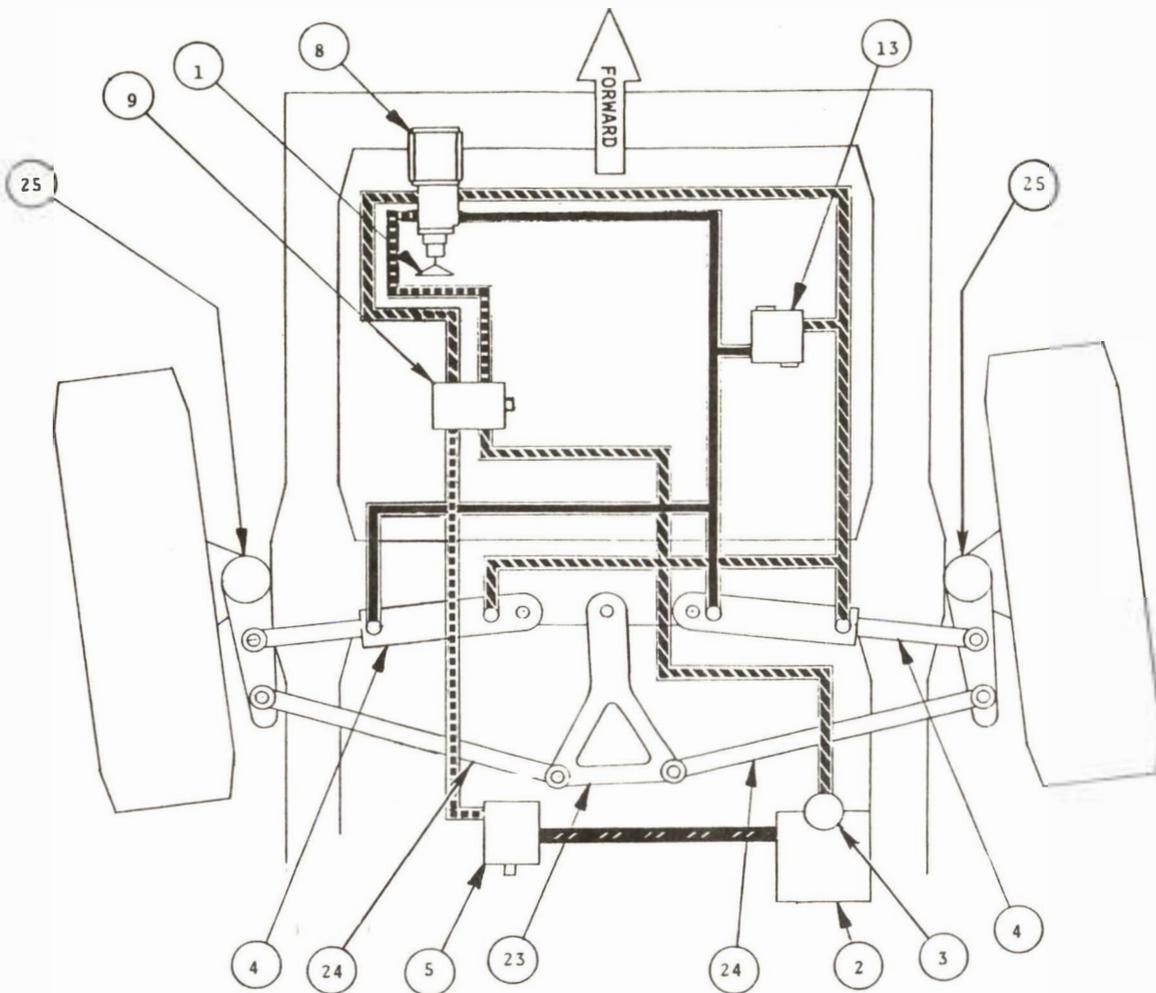




- Ⓐ ROTATES IN Ⓒ AND Ⓐ TRANSLATES
- Ⓑ ROTATES WITH Ⓐ AND SLIDES IN Ⓐ
- Ⓓ TRANSLATES WITH Ⓐ AND ROTATES ON Ⓐ
- Ⓔ ROTATES TO TRANSLATE Ⓒ, Ⓐ, AND Ⓓ

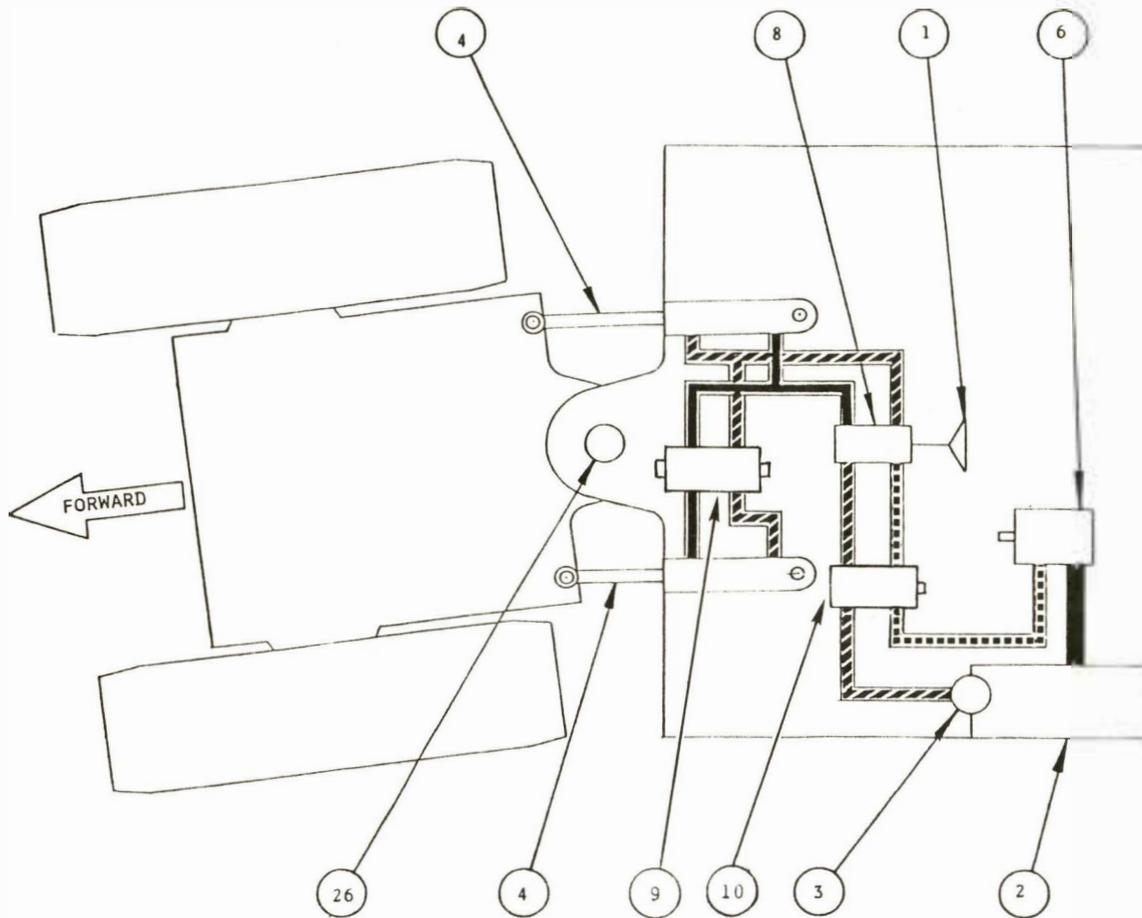
- ROTATION OF Ⓐ AND Ⓑ TRANSLATES Ⓓ SHIFTING STEERING CONTROL VALVE SPOOL INITIATING STEERING.
- FEEDBACK ROTATES Ⓔ AND TRANSLATES Ⓒ, Ⓐ, AND Ⓓ RETURNING STEERING CONTROL VALVE SPOOL TO NEUTRAL.

Figure 39. Mechanical Servo-Linkage Employed in Hydrostatic Steering Systems Employing Hydromechanical Feedback to the Steering Control Valve



- | | |
|-----------------------------|----------------------------|
| 1. STEERING WHEEL | 23. BELLCRANK ARM ASSEMBLY |
| 2. HYDRAULIC OIL TANK | 24. TIE ROD |
| 3. FILTER | 25. KING PIN |
| 4. STEERING CYLINDER | ▬ SUPPLY |
| 5. FIXED DISPLACEMENT PUMP | ▬ ACTUATING PRESSURE |
| 8. HAND METERING PUMP/VALVE | ▬ RETURN |
| 13. SHOCK LOAD CHECK VALVE | ▬ AUXILIARY SYSTEM |
| | ▬ PUMP SUPPLY |

Figure 40. Hydrostatic Steering System Using Hand Metering Pump/Valve Without Feedback – Open Center (Left Turn Mode)



- | | |
|-----------------------------|---------------------------------------------------------------------------------------------------------|
| 1. STEERING WHEEL | 10. RELIEF VALVE |
| 2. HYDRAULIC OIL TANK | 26. ARTICULATION POINT |
| 3. FILTER |  SUPPLY |
| 4. STEERING CYLINDER |  ACTUATING PRESSURE |
| 6. VARIABLE VOLUME PUMP |  RETURN |
| 8. HAND METERING PUMP/VALVE |  PUMP SUPPLY |
| 9. SHOCK LOAD CHECK VALVE | |

Figure 41.. Hydrostatic Steering System Using Hand Metering Pump/Valve Without Feedback – Closed Center with Variable Volume Pump (Left Turn Mode)

or closed center hydraulic circuit. Feedback is not required since the operator is directly connected from the steering wheel to the steering cylinders by a column of hydraulic oil rigidly contained within the steering hoses. The power amplification concept is explained below.

Hydraulic oil is delivered to the hand metering pump/valve from either an open center hydraulic circuit (shown in Figure 40) or from a closed center hydraulic circuit (shown in Figure 41). The spool and sleeve and porting within the hand metering pump/valve determines the circuit configuration. The hydraulic oil is passed through the ports in this device to a metering section. This metering section is composed of cavities that rotate with the input shaft. The oil is directed into these cavities and then passed from the inlet port in the pump/valve to the selected cylinder port and thence to the steering cylinders where it actuates the steering cylinders. Return oil from the other end of the steering cylinders is returned to the system tank in the same manner. Thus, in operation the hand metering pump/valve meters precise volumes of hydraulic power to steering cylinders.

Figure 42 shows a section through a typical hand metering pump/valve identifying the various components. It should be noted that the steering shaft, spool, sleeve, and drive gear are mechanically linked together. Whether the pump/valve is considered open center or closed center depends on the configuration of the spool and sleeve. Turning the steering shaft turns the spool. The sleeve is linked to the spool through a spring connection and the spool will turn a few degrees before the sleeve begins to rotate. This lines up ports in the sleeve with oil passages in the spool. The hydraulic oil is then directed from the hydraulic pump through ports in the metering pump/valve body then through ports in the sleeve and then through passages in the valve body and



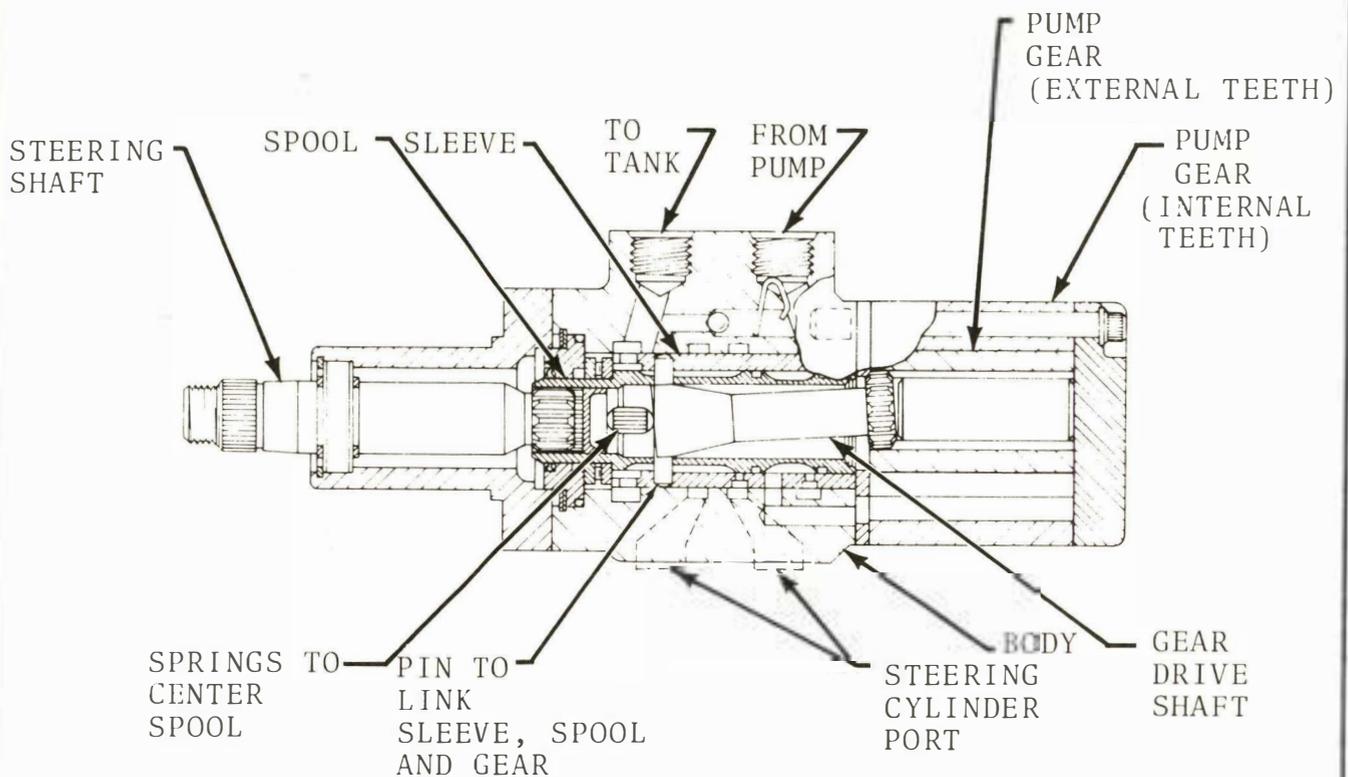


Figure 42. Section Through a Typical Hand Metering Pump/Valve Assembly

finally to the metering chamber which is also called the gear section or gerotor assembly. As the metering section rotates, the oil is metered and fed back through the valve body, back through the sleeve, through passages in the spool and directed to the chosen cylinder port just as in the operation of a standard four-way valve. When turning action from the steering shaft ceases, the springs realign the spool within the sleeve blocking the cylinder ports and the recentered spool will determine the proper hydraulic circuit configuration (open or closed center).

Figure 43 shows a section through the gerotor gear assembly. It should be noted that there are six teeth on the driven gear and seven teeth on the internal gear. The driven gear is of smaller diameter and turning the steering

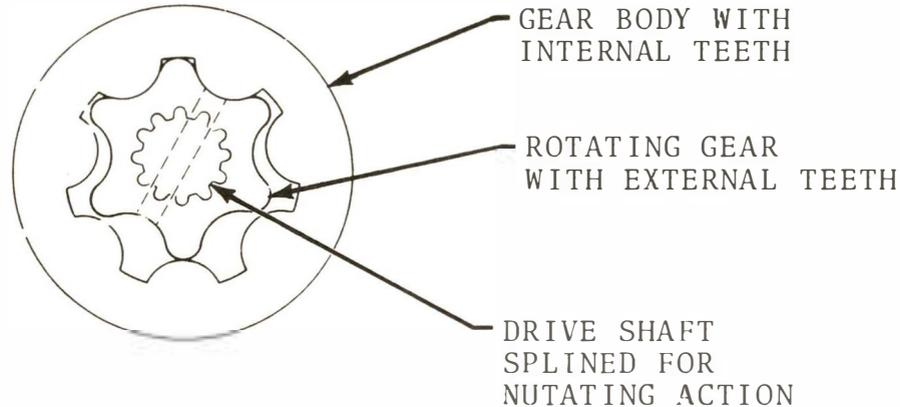


Figure 43. Section Through Hand Metering Pump/Valve Gear Assembly

shaft causes its center to nutate (travel a circular path) around the center of the internal gear. The surface of the driven (rotating) gear actually rolls around the surface of the internal gear much like a gear rolling on a toothed rack. The rolling action traps a specific volume of oil (metered volume) in front of each tooth and therefore, the metering pump/valve exhibits a specific displacement. The hand metering pump/valve will operate in either direction.

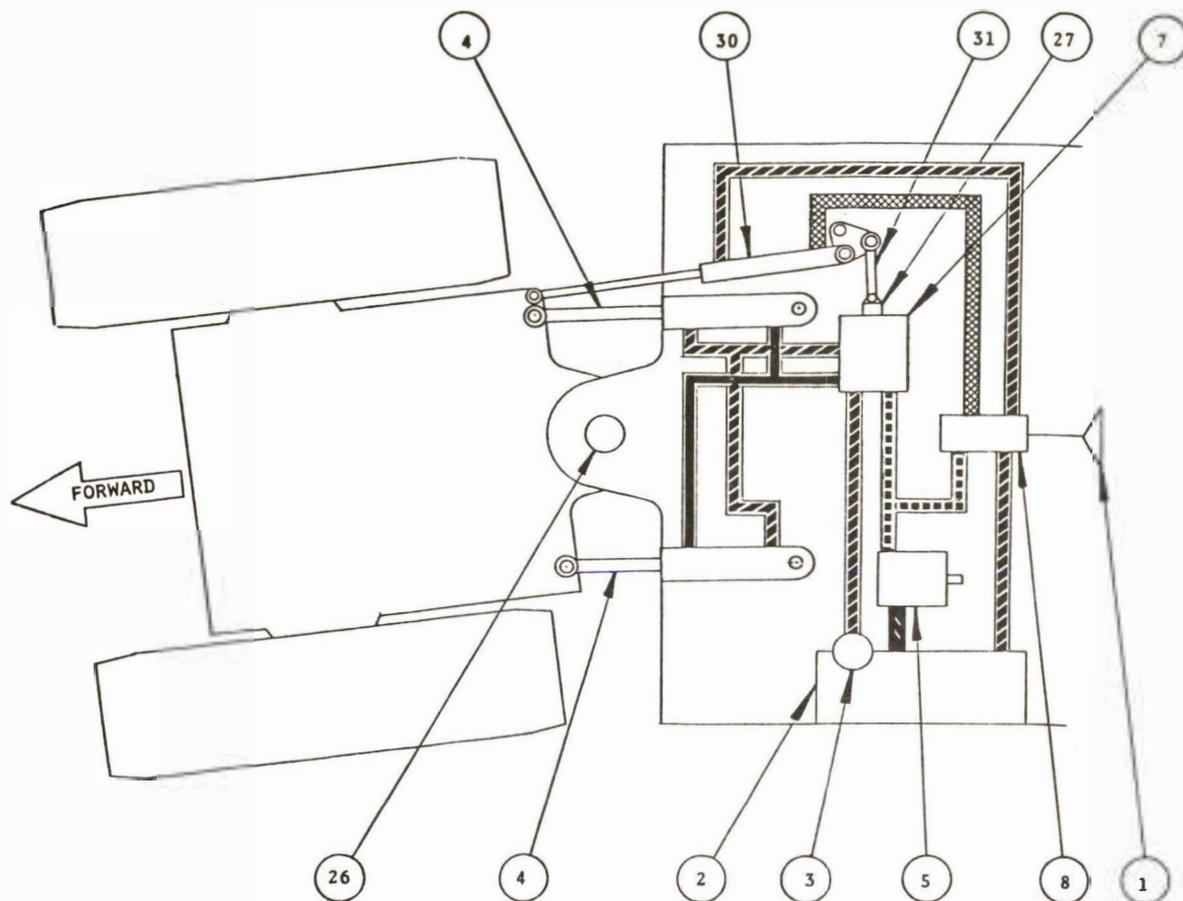
The hand metering pump/valve may also be operated manually to supply emergency steering power. In typical applications, 100 foot-pounds of torque supplied to the unit from the steering wheel will operate a 10 cubic inch per revolution displacement device and supply oil at 1000 psi. This pressure may or may not be sufficient to operate the steering cylinders enough to be considered adequate for emergency steering. Ten cubic inches is considered an upper size limitation. The rate of delivery of the oil will of course depend upon the operator's physical capabilities. Emergency steering using this device will be discussed later in this report.

Hydrostatic steering systems incorporating hand metering pump/valves without feedback may be found on the following equipment:

- Terex 33-11, 33-15, and 33-09 Haul Trucks
- Unit Rig Mark 33 Lectra Haul Truck
- Unit Rig Mark 36 Lectra Haul Truck
- Dart 3100 Haul Truck
- Euclid R-85, R-100, and R-170 Haul Trucks

A hydrostatic steering system wherein a hand metering pump/valve operates a separate steering control valve that is servoed with mechanical feedback is shown in Figure 44. The accompanying hydraulic circuit may be either open or closed center. In operation, the hand metering pump/valve meters a specific volume of oil to the steering valve spool control cylinder (feedback cylinder). One end of the steering valve spool control cylinder is pinned to the steering valve spool and the other end is pinned to the opposite vehicle half. As the metered oil is supplied to this cylinder, it either elongates or contracts depending upon whether the oil is fed to the head end or rod end, and the steering valve spool is shifted. Hydraulic power is now directed to the steering cylinders and steering action commences and the steering linkage moves. The steering valve spool control cylinder (feedback cylinder) is now translated mechanically and recenters the spool in the steering control valve. This is the mechanical feedback aspect of the system.

This system is typically used on articulated vehicles when mechanical steering linkages become complex and where hand metering pump/valve sizes are not capable of handling



- 1. STEERING WHEEL
- 2. HYDRAULIC OIL TANK
- 3. FILTER
- 4. STEERING CYLINDER
- 5. FIXED DISPLACEMENT PUMP
- 7. STEERING CONTROL VALVE
- 8. HAND METERING PUMP/VALVE
- 26. ARTICULATION POINT

- 27. STEERING CONTROL VALVE SPOOL
- 30. FEEDBACK CYLINDER
- 31. CONTROL VALVE SPOOL LINKAGE
- ▨ SUPPLY
- ▬ ACTUATING PRESSURE
- ▬ RETURN
- ▨ PILOT PRESSURE
- ▨ PUMP SUPPLY

Figure 44. Hydrostatic Steering System with Hand Metering Pump/Valve Operating a Separate Steering Control Valve with Mechanical Feedback – Open or Closed Center (Left Turn Mode)

the flow rates required. It should be noted that it is not possible to use the hand metering pump/valve by itself for emergency steering in this system configuration. This steering system configuration may be found on the following representative equipment:

- Terex 72-71 Loader
- Terex 72-81 Loader

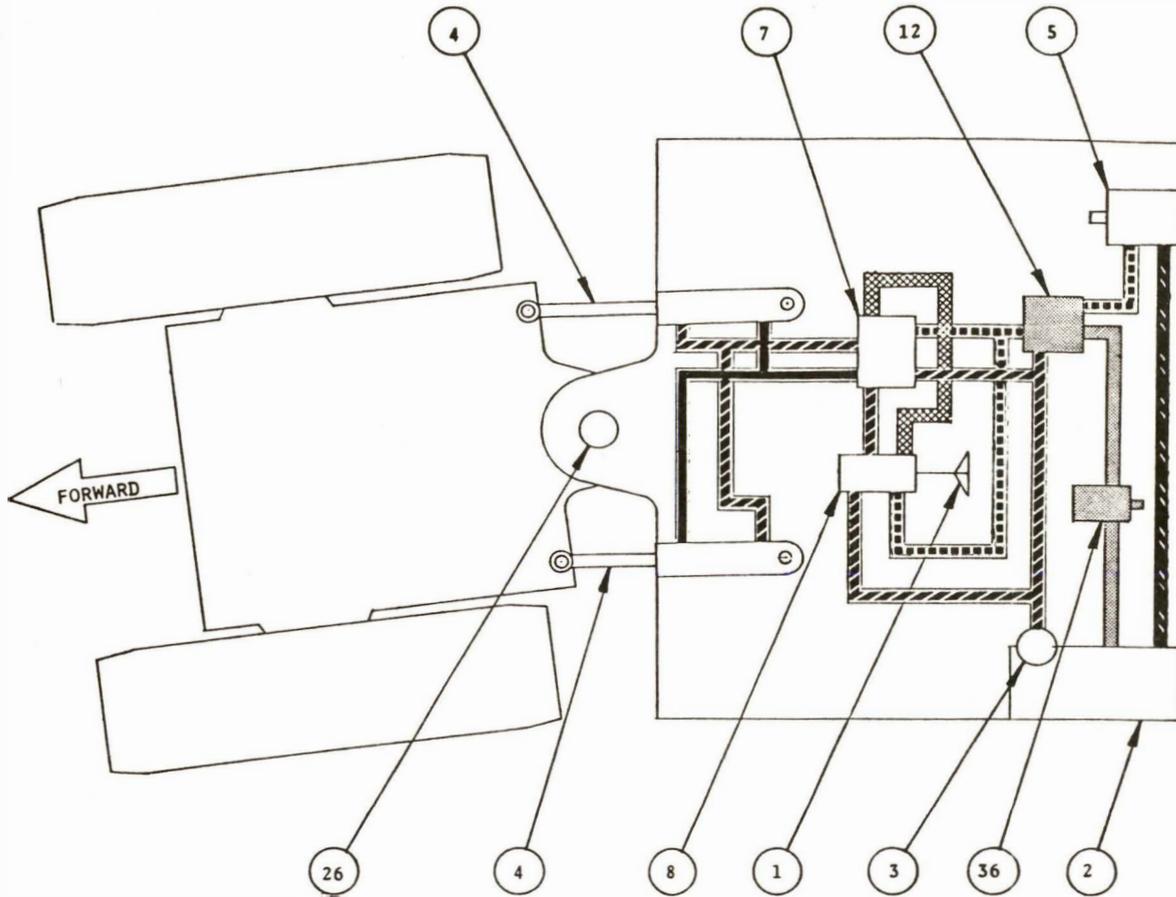
A hydrostatic steering system wherein a hand metering pump/valve operates a separate steering control valve that is servoed with hydraulic feedback is shown in Figure 45. The accompanying hydraulic circuit may again be either open or closed center. In operation, the hand metering pump/valve meters a specific volume of oil to the steering valve spool control cylinder. It should be noted that the lines carrying this oil continue on to the feedback cylinder. The metered amount of oil moves the spool in the steering valve, hydraulic power is supplied to the steering cylinders, and steering action commences. The feedback cylinder is mounted between vehicle frame halves which results in elongation or contraction of the feedback cylinder during the steering action. Oil is therefore displaced from the feedback cylinder, directed back to the steering valve spool control cylinder, and recenters the spool in the steering valve stopping the steering motion. This is the hydraulic feedback aspect of the system. To reiterate, the hand metering pump/valve shifts the spool in the steering control valve, and the hydraulic feedback cylinder shifts and then recenters the spool when the desired amount of steering motion has been achieved.

This system is also typically used on articulated vehicles to eliminate complex mechanical linkages and when the flow rates exceed the capacities of standard hand metering pump/valves. It should be noted that the hand metering pump/valve by itself may not be used for emergency steering with

this system configuration. This steering system configuration is found on the John Deere 860A Scraper.

A hydrostatic steering system wherein a small hand metering pump/valve operates a separate higher flow steering control valve without position feedback is shown in Figure 46. The steering control valve used in this system is a pilot operated, spring centered, pressure compensated, four-way valve. Turning the steering wheel at a certain rate causes the hand metering pump/valve to deliver a specific flow rate of pilot oil to the appropriate end of the spool in the steering control valve. Metering orifices at the end of the spool cause a pressure unbalance causing the spool to shift and open the appropriate cylinder port to system flow. This cylinder flow is pressure compensated and has a preset maximum flow rate. The faster the steering wheel is turned, the larger the pressure drop is across the metering orifices, resulting in the spool being shifted further for faster steering. Cylinder flow is limited by a preset valve and is independent of center load or rolling resistance. When the steering wheel rotation is stopped, pilot flow stops, eliminating the pressure unbalance necessary to keep the spool shifted. The centering spring quickly returns the spool to the neutral position. There is no feedback to recenter the spool with this action being controlled by metering orifice pattern, centering spring and oil viscosity.

This system is used on articulated machines to eliminate false feedback signals generated by wear in traditional feedback components and machine control linkages. Pilot control to cylinder flow ratios range from 7 to 62. Special valving will permit automatic manual steering by the hand metering pump/valve on small machines. The factors which limit manual steering are steering cylinder volume, machine weight and the hand metering pump/valve size. It should be



- | | |
|------------------------------------------------|---------------------------------------------------------------------------------------------------------|
| 1. STEERING WHEEL | 26. ARTICULATION POINT |
| 2. HYDRAULIC OIL TANK | 36. GROUND DRIVEN AUXILIARY PUMP |
| 3. FILTER | |
| 4. STEERING CYLINDER |  SUPPLY |
| 5. FIXED DISPLACEMENT PUMP |  ACTUATING PRESSURE |
| 7. PRESSURE COMPENSATED STEERING CONTROL VALVE |  RETURN |
| 8. HAND METERING PUMP/VALVE |  PILOT PRESSURE |
| 12. DIVERTER VALVE |  AUXILIARY SYSTEM |
| |  PUMP SUPPLY |

Figure 46. Hydrostatic Steering System with Hand Metering Pump/Valve Operating a Separate Steering Control Valve without Feedback – Open or Closed Center (Left Turn Mode)



noted that on large machines the hand metering unit and an emergency steering pump as shown in Figure 46 are used in the event of engine failure. This steering system configuration is found on the following equipment:

- Caterpillar 950 Wheel Loader
- Caterpillar 966C Wheel Loader
- Caterpillar 980B Wheel Loader
- Caterpillar 992B Wheel Loader

3.5 EMERGENCY, SUPPLEMENTARY, AND AUXILIARY STEERING SYSTEMS

Hydrostatic steering systems depend on hydraulic power amplification for operation. It is feasible to manually steer the relatively light vehicles employing power assisted mechanical steering systems but it is not feasible to expect operators to supply the force required to steer a large haulage truck, scraper, or front-end loader. The hydraulic pump supplying the steering system is typically driven by the vehicle engine, therefore, engine failure results in loss of steering. It is obvious that an emergency or auxiliary steering system must receive its power input from a separate power source or must store suitable hydraulic power (pressurized oil). Three emergency steering concepts are in common use. These are:

1. A separate hydraulic pump driven by an electric motor operating off the vehicle battery system,
2. A separate hydraulic pump driven by a shaft from the vehicle differential or transmission which is in turn motivated by the road wheels (or is "ground driven"), or
3. Incorporation of a suitably sized oil accumulator in the hydraulic steering circuit whereby

sufficient quantities of pressurized hydraulic oil are made available to the steering system after pump failure, to perform a limited amount of steering activity.

Some of the advantages and disadvantages of these three systems are shown in Table 3.

Figures 47, 48 and 49 show how these emergency systems are incorporated into the primary steering system hydraulic circuit.

The battery driven emergency steering system is typically activated by a switch located on the control console although some later model machines have automatic activation in the event of engine failure. The manual type switch is typically covered in a manner providing ease of operation but precluding accidental operation. An "On" light may or may not be provided.

Most mining and construction machines utilize 24-volt electrical systems. It is feasible to draw 500-1000 amps from such systems for periods of 2-5 minutes. This can provide 5-15 horsepower. However, extended operation at the 500-1000 amp level will soon destroy the compact motor used on most emergency steering systems rendering the system useless until it is repaired. Prudent use of battery driven emergency steering is required. The battery driven system is truly an emergency system and not an auxiliary system.

The available power is also a function of battery condition. High current is only available from well charged batteries maintained in good condition. Battery performance can be severely degraded by cold weather.

Ground driven pumps are usually sized so that they are capable of supplying a high percentage of the steering



Table 3. Advantages and Disadvantages of Emergency Steering Systems

System	Advantages	Disadvantages
Battery Driven Pump	<ul style="list-style-type: none"> • Easy to install • Easy to inspect • Easy to maintain • Easy to operate 	<ul style="list-style-type: none"> • Limited power • Electrical failure causes emergency system failure • Limited duty cycle • Batteries must be maintained to be available • Subject to misuse • Dependent on operator action if not automatically activated
Ground Driven Pump	<ul style="list-style-type: none"> • Most designs are active • Easy to maintain • Requires no operator action in emergency • Unlimited duty cycle 	<ul style="list-style-type: none"> • Limited output at low vehicle speed • No output when stopped • Difficult to inspect during preshift check • Indication of main power supply failure dependent on operator awareness
Accumulator System	<ul style="list-style-type: none"> • Always active • Easy to inspect • Little degradation of steering in emergency operation • Requires no operator action in an emergency • Easy to maintain 	<ul style="list-style-type: none"> • Generally requires closed center hydraulic circuit • Requires automatic accumulator bleed-down • Requires maintenance of gas charge • Limited steering time and activity and then no capability • Indication of main power supply failure dependent on operator awareness

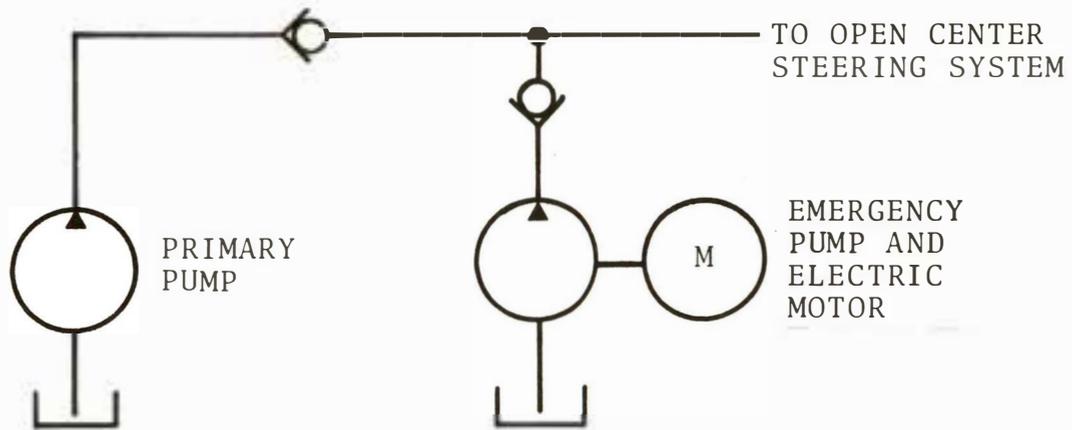


Figure 47. Typical Incorporation of a Battery Driven Pump in a Hydrostatic Steering System

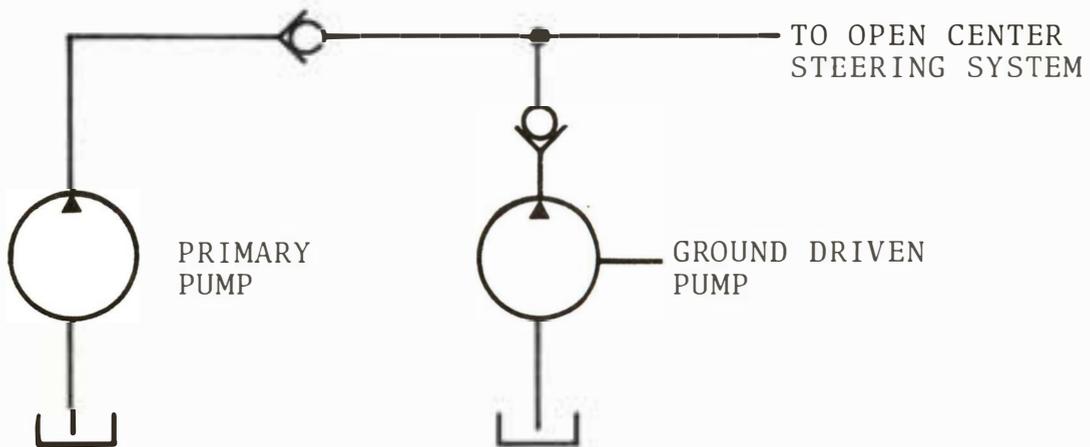


Figure 48. Typical Incorporation of a Ground Driven Pump in a Hydrostatic Steering System

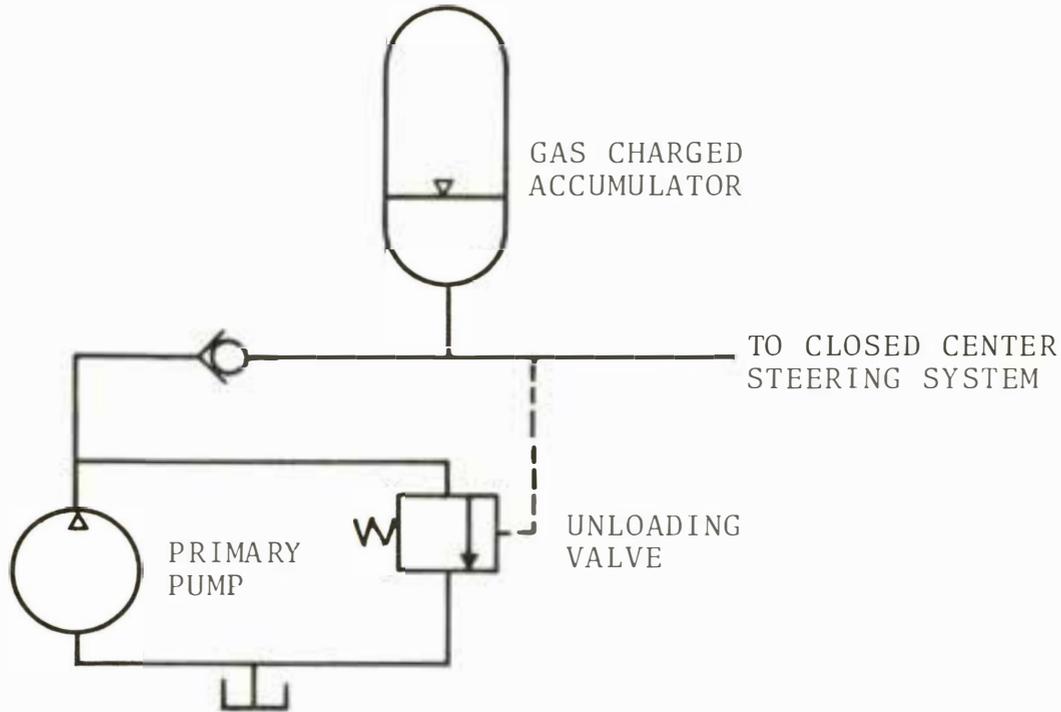


Figure 49. Inclusion of a Gas Charged Accumulator to Continue to Supply Pressurized Hydraulic Oil When Primary Pump Fails (Accumulator Emergency System)

oil under normal operation when the vehicle is operating at "roading" speeds. Since the volume of the pump is directly proportional to the speed of rotation and since the speed of rotation of the pump is directly related to the road speed, it may be noted that if a machine is operating at 25 percent of normal road speed, then the hydraulic flow rate will be 25 percent of normal and the rate of steering will be limited.

The use of an accumulator to supply emergency steering hydraulic power after pump failure requires the use of the closed center hydraulic circuit incorporating either a fixed displacement pump with unloading valve or a variable volume pump. An operating pump is required to recharge the accumulator and once the stored volume of oil has been consumed, there is no energy available and the emergency capability

ceases to exist. A correctly sized system precludes this occurrence. The emergency capabilities of an accumulator system may be best shown by the following example:

A 20-gallon accumulator pre-charged to 1000 psi and fully charged to 2000 psi maximum pressure can theoretically supply up to 10 gallons (2310 cubic inches) of oil at pressures ranging from initial 2000 psi down to 1000 psi. This is enough oil to drive a pair of 5-inch diameter cylinders with 2-inch diameter rods and a 21-inch stroke approximately three full cycles. This would turn the machine road wheels three turns lock-to-lock.

Three full steering excursions provide a significant amount of machine mobility and should provide adequate steering capability to effect the safe stop of a moving vehicle.

One disadvantage of the accumulator emergency system is the fact that loss of primary hydraulic power may go unnoticed if the failure is only in the pump and a warning is not provided. Steering capability does not degrade noticeably or rapidly and the ultimate warning to the operator may well be the total loss of steering capability. Audible or visual warning signals should be built into this system as well as the battery driven pump system and the ground driven pump system.

SECTION 4.0

STEERING-RELATED ACCIDENT INFORMATION

The Mine Safety and Health Administration (MSHA) requires an accident report form be completed and filed with the MSHA-Health and Safety Analysis Center in Denver, Colorado for mine accidents that result in a fatality or in an injury that prevents the miner from returning to work on his next work shift. Woodward Associates, Inc. has worked closely with MSHA-HSAC on previous USBM projects; the Center continued its excellent cooperation and allowed extensive examination of the reports available on accidents occurring in coal and metal/nonmetal mines. The following sets of MSHA accident records were studied:

- Accidents resulting in a fatality
 - Metal/Nonmetal Mines – All accidents recorded for 1976 and 1977.
 - Coal Mines – All accidents recorded for 1976 and 1977.
- Accidents resulting in a nonfatal injury that were investigated by MSHA
 - Coal Mines – All accidents recorded for 1976 and 1977.
- Accidents reported to MSHA by mining companies
 - Coal Mines – All accidents reported for 1976 involving front-end loaders, dozers, scrapers, and haulers.

Initial planning had also included the review of nonfatal accident records for metal/nonmetal mines for 1976 and 1977 and for coal mine injury accidents for 1977. The low number of steering-related accidents identified in the accident record sets examined indicated that there would be little benefit to be gained from continued searching of the MSHA accident records. For example, of 993 coal mine accidents involving mobile equipment reported to MSHA in 1976, there were 3 accidents that are clearly steering-related and 8 that are "loss of control" accidents that might have been caused by a steering-related problem. These figures do not necessarily represent an absence of accidents caused by steering problems. The fact is that the accident investigation and accident recording methodology used by MSHA will not necessarily identify the cause of the accident but will identify the "result" of the cause and will identify the safety device or safety practice that would prevent the injury. An example would be as follows: a front-end loader tramping backwards from a haulage truck loading area to the maintenance yard at 20 mph "loses control" and runs off the haul road and overturns three times. The operator is seriously injured. The MSHA report would identify the operator's action of tramping backwards at 20 mph as an unsafe operating procedure (true!), the overturning of the front-end loader as the cause of the operator's injuries (true!), and the need for rollover protective structures to protect the operator as an important piece of safety equipment (true!). However, it will not indicate that the steering system is too sensitive for such high speed operation; is not designed for high speed operation in reverse; or if the machine is unstable at such high speeds. The report may or may not contain reference to the condition of the terrain or the road. Did the machine strike a rut causing the operator to lose control? Would a steering system requiring



less steering effort (rim pull) have allowed the operator to maintain control even though he was operating in an unsafe manner? Therefore, it was concluded that these reports could not pinpoint specific steering defects or deficiencies.

All accidents resulting in fatalities are investigated by MSHA. The following summaries describe four fatalities that were either caused by steering problems or loss of control. These are from MSHA records for 1976 and 1977.

June 12, 1976: At a mine in Fort Totten, North Dakota, the victim was backing his 1966 front-end loader down a haul road. He ran off the road and overturned 180 degrees. Apparently he lost control at high speed. The front-end loader had a fiberglass cab, but no ROPS and no seat belt. Victim was 58 years old. He had 20 years' experience in mining and 20 years as a machine operator.

September 27, 1976: At a mine in North Carolina, the victim was backing his 1962 front-end loader with the bucket raised. He lost control and rolled 270 degrees. Victim either jumped or was thrown from the machine. The front-end loader did not have a ROPS or seat belt. Victim was 35 years old. He had 2-1/2 years' experience in mining and as a front-end loader operator.

April 11, 1977: At a mine in Herndon, Virginia, the victim was killed when he jumped or fell from the hauler he was operating and was run over by the rear wheels. In this crushed stone mine, blasted stone was loaded by a front-end loader into end-dump haulers. The victim had been hauling 1/2 loads of crusher run stone into the quarry to make smoother haul roads. At 4:55 p.m. (almost 10 hours after start of shift at 7:00 a.m.) the victim was driving up a 7 percent grade (width 40 feet, with a boulder berm, 3 to 5 feet square). While downshifting, he accidentally pulled the shift lever into reverse, killing the engine of his 27-ton hauler (age not given). Unable to steer without the power steering, he applied the air brakes at least twice. The hauler traveled in a straight course about 280 feet before dropping over the 40-foot quarry wall. About 50 feet before the edge, the victim jumped or fell from the truck. His torso and head were crushed by the left dual wheels. The victim was 23. He had about 5-1/2 months of mine experience, but only 11 days since 1973. The investigative report indicated that he was insufficiently trained as a driver.

April 14, 1977: At a mine near Florence, Colorado, the victim was killed when his front-end loader left the road, overturned and crushed him. A new concrete road, 30 feet wide with a 3-5 degree rise and no berm, was being constructed. The victim was on this road, driving to a refueling point when he lost control. The front-end loader was a 1959 model. It had no ROPS or seat belt. Its hydraulic steering was not operating properly, according to post-accident examination of the machine. The inspector also noted that "the small tire on the right side" of the front-end loader "was worn out," although it did not fail during the accident. Victim was 31. His mining experience was 7 years. He had worked as a truck driver and front-end loader operator at this mine for two years and seven months. The accident happened at about 4:30 p.m., approximately 1-1/2 hours after start of shift.

Two of the above accident summaries clearly state that the steering system contributed to the accident. The other two state that loss of control is the cause of the accident. Both loss of control accidents were experienced by front-end loaders tramping backwards.

Injury-producing accidents in coal mines in 1976 recorded by MSHA that appear to be steering-related are listed below with the short description given in the accident report.

Steering-Related Accidents

4-27-76 2:00 p.m. Jackson, KY

Truck driver, driving truck. Engine stalled causing loss of brakes, steering and control.

7-24-76 1:30 p.m. Drakesboro, KY

Truck driver, 41 years old, driving water truck. Steering failed after making a turn.

11-6-76 1:30 p.m. Ethel, WV

Truck driver, driving coal haulage truck. Front wheel broke. Suffered bruised chest. One day lost.

Loss of Control Accidents

1-20-76 9:00 p.m. Hartford, KY

Truck driver, 33 years old, lost control of truck and turned over. Suffered shattered jaw and lacerations of head.

6-29-76 12:25 p.m. Inez, KY

Truck driver, 18 years old, lost control and jumped. Suffered contusions and lacerations on head.

10-5-76 8:30 a.m. Hartford, KY

Truck driver, 21 years old, lost control while going around corner. Suffered cut lip and bruises. One-half day lost.

10-14-76 12:00 a.m. Jackson, KY

Truck driver, 29 years old, lost control. Suffered broken knee cap.

11-27-76 7:00 p.m. Greenville, KY

Shooter, 34 years old, lost control of truck, hit head on radio speaker. Suffered cuts and bruises.

12-29-76 2:15 p.m. Beckley, WV

Truck driver, 39 years old. Engine died, lost air pressure and ran into front-end loader. Suffered bruised knee.

A summary of information gathered from the examination of MSHA-HSAC accident records is given in Table 4. This table provides an interesting comparison of several accident types. Steering-related accidents are about one percent of the accidents examined.

The second primary source of accident or hazardous incident records was the Ministry of Mines and Petroleum Resources, Victoria, British Columbia.

The British Columbia Coal Mines Regulation Act and Mines Regulation Act requires that all dangerous and/or unusual occurrences at a mine be reported to the Inspector of Mines and the Chief Inspector within 24 hours of the incident. These incidents/accidents may not have caused injury or death to mine

Table 4. MSHA-HSAC Accident Data

	1976-77 Metal/ Nonmetal Fatal Fatal	1976-77 Coal Fatal	1976-77 Metal/ Nonmetal Nonfatal Investigated	1976-77 Coal Nonfatal Investigated	1976 Front-End Loader HSAC Data Bank	1976 Hauler HSAC Data Bank	1976 Dozer/ Scraper HSAC Data Bank	Totals
Accidents involving mobile equipment (except rail)	47	62	12	18	158	370	354	1021
Rollovers and other related accidents	18	10	4	6	28	52	83	201
Slips/falls related to ladder equipment ingress/egress	0	1	2	1	74	60	128	266
Falling material	6	32	1	2	0	0	29	70
Steering-related accidents	3	1	0	0	0	9	0	13



personnel. The Ministry of Mines and Petroleum Resources prepares short summaries of these incidents. Mr. Vic Dawson of the Ministry volunteered to provide information from his files covering 1972 through 1977. The following summaries cover the steering-related incidents recorded for those six years.

Incidents Recorded During 1972

On April 7 at a Benson Lake operation, the steering mechanism of a truck failed as it emerged from the decline portal. The driver jumped free, uninjured when the truck traveled up a bank at the edge of the road and then rolled over. The tie-rod linkage separated when a nut had stripped its thread.

On September 10, the right front wheel spindle snapped on a loaded 150-ton truck as it was turning while traveling about 5 miles per hour on a haul road. The investigation indicated the fracture had developed along an initial fatigue crack. A failure such as this shows the potential value of regular nondestructive tests.

In mid-October, at a waste dump, one of the front wheels fell off a loaded 100-ton truck as it was backing up. An investigation indicated the fracture of the ball stud holding the front wheel casting of the steering linkage. This permitted the wheel to veer away from the direction the truck was moving and the increased load imposed snapped the wheel spindle.

On October 20, on the main haulage road to a mine, a loaded 35-ton truck ran away down a hill, struck a bank and tipped over. The truck box had been partly elevated in order to spread fill material for road repair. The transmission was in neutral position. The driver attempted to accelerate the engine to raise the box but the engine stalled permitting a failure of the power steering which continued when the driver neglected to engage the emergency steering switch. In addition the two attempts made to restart the engine so depleted the air supply that although the brakes "dynamited" they failed to hold the vehicle. Braking was further reduced by an accumulation of asbestos mud and fibre on the brake drums and shoes. It is believed the engine did not restart because the operator had depressed the accelerator in such a manner as to actuate the engine shut-off control connected by linkage to the accelerator. The operator failed to reset the control before attempting to restart the engine.

On December 9, at an open pit mine, the right front wheel of a loaded 50-ton truck fell off as it was being backed up the dump ramp. An investigation of the incident indicated a fatigue failure of the outer tapered wheel bearing.

Incidents Recorded During 1973

On January 6 the driver of an empty 120-ton truck drove the vehicle off a road and into a 5-foot deep drainage ditch. The driver claimed the brakes and emergency steering had failed to function although an examination of the vehicle showed them to be serviceable.

On July 8 while descending the main haulage ramp the engine of a 100-ton truck stalled and the driver forgot to engage the emergency steering system. The vehicle was almost stopped with the service brake but with the driver being unable to steer, the truck continued to the road edge where it slid over the edge and rolled down a 39-foot embankment, landing upside-down. It could not be determined what caused the engine to stall.

On August 8 the driver of a haulage contractor's truck drove off the road and in so doing he received multiple lacerations and a broken left ankle as the truck rolled over and down the hillside. The driver reported the engine had stopped and steering ability was lost. The investigation completed indicated the engine was stopped, the gear shift in neutral and the brakes were overheated. The vehicle recorder indicated the possibility that the truck was being operated at a speed in excess of that posted for the road.

Incidents Recorded During 1974

On June 15 a dump truck loaded with crushed rock overturned on the townsite road at an underground mining operation. The accident was attributed to the vehicle traveling too fast to negotiate a switch back. It is possible the accident may have been attributed to vehicular steering and braking inadequacies.

On August 7 at an open pit mine a loaded truck being driven downgrade failed to complete a right turn, crossed the road and ran up on a bank of loose muck where it overturned. The driver claimed the vehicle seemed to have a tendency to pull to the left but a mechanical examination failed to reveal any faulty condition except some stiffness in the steering action.

On September 2 at an open pit mine the universal joint failed in a grader as it was descending a ramp. The operator applied brakes without effect and the vehicle ran out of control for



about 150 feet when it collided with a haulage truck. Both vehicles were extensively damaged but the drivers suffered only minor injuries. The grader operator had radioed that his vehicle was descending out of control but the driver of the truck did not hear the warning. The brakes were inoperative because the hydraulic pumps for pressurizing the transmission, steering and brakes are driven by the shaft on which the universal joint failed. The grader is being repaired to provide positive emergency steering and brakes in the event of another similar universal joint failure.

On September 9 at an open pit mine the driver of a truck found he had no steering in the vehicle but managed to stop without incident. He had picked the vehicle up from the repair shop where it had been taken for a correction of steering malfunction, however, the vehicle had not been tagged out of service as required.

On October 12 the driver of a loaded haulage truck at an open pit mining operation advised that the steering locked as the truck was proceeding down hill. The truck ran into a ditch and rolled onto its left side. The driver had noted in the logbook that the steering appeared faulty but did not report the condition to anyone.

Incidents Experienced During 1975

On March 2 as a front-end loader was being driven down a road inclined at 9 percent, to a crushed rockpile during a snow-storm at an open pit mine, the loader veered to the right and ran off the road. The driver said the vehicle did not respond to steering or brakes even though he pushed the brake pedal to the floor. The investigation showed the brakes to have been in good working order and that no skid marks were on the road where the loader had traveled. It is possible tire chains would have provided better traction and it is the intention of management to give future loader operators formal driving training.

On March 12 at an open pit mine a loaded 100-ton truck ran out of control, struck a sand pile in the middle of the road, then climbed a grader windrow of sand and gravel and finally stopped about 40 feet from the road. Although the driver claimed he experienced steering difficulties he made no attempt to use the emergency steering with which the truck was equipped. An investigation indicated that the left front suspension was badly damaged, the left front steering-cylinder piston rod was broken and the hydraulic steering pump housing was cracked during the mishap. It is believed the driver fell asleep and the damages occurred as a result of the truck being out of control.



On March 19 the front wheel spindle broke on the driver's side of a large haulage truck. As this type of incident has occurred elsewhere it is recommended that a regular program of nondestructive testing be carried out on all wheel spindles. Meanwhile it is the mine operator's intention to have a metallurgical test made on the broken components as they and other spindles have developed fatigue cracks.

On July 9 an unloaded 100-ton haulage truck went out of control and struck a pole-type cable arch on a turn at the bottom of a ramp leading into an open pit. The driver reported he had lost steering control but no steering defects were found. It is believed the vehicle was traveling too fast on the muddy road surface and it had skidded and thus did not respond to steering control.

On October 19 the right front wheel suspension bolts on an open-pit coal haulage truck fractured in fatigue failure while in operation. No injury resulted and the bolts were replaced to a high tensile steel type having a stress rating of 150,000 psi.

On October 26 the right front wheel suspension bolts on an open-pit coal haulage truck fractured in fatigue failure while in operation. No person was injured and the bolts were replaced with the same type as used in the October 19 incident.

On December 6 two right front wheel spindle failures were recorded at an open-pit coal mining operation. In both instances the failures occurred while the haulage trucks were executing tight turns.

Incidents Experienced During 1976

On January 14 a ball stud on the steering mechanism broke on a large open-pit haulage truck as it was driving along a mine road. Steerage was lost and the vehicle ran through a berm near the road edge and continued into a sand impact barrier on a corner above a canyon. The impact barrier successfully halted the vehicle which would otherwise have gone down into the canyon.

On February 5 a 100-ton ore truck traveling at a speed of 20 mph lurched to the left and commenced to run off the open pit haulage road. When this happened the driver applied the brakes and attempted to turn to the right but found the steering to be very stiff. The vehicle ran through the safety berm at the road side, became airborne for about 10 feet and then struck a sand impact barrier, where it stopped about 8 feet from the edge of a canyon. On examination, the ball stud on

the right steering ram was found to have broken at the site of an old crack. In addition, the truck frame was found to have broken on both sides, the cab roof crushed in and the decking damaged, however, the driver was not injured. The investigation was unable to determine why there was a complete lack of steering control but it did demonstrate that the impact barrier had undoubtedly prevented the vehicle from dropping into the canyon.

On April 7 a steering failure occurred in a loaded 50-ton truck. The truck rammed a rock bank and caused a failure in a hydraulic control valve. No person was hurt and the investigation indicated that the spiral shaft stud had broken, thus allowing free movement of the wheels.

On March 30 a failure occurred in the left front suspension of a loaded 100-ton open pit haulage truck as it was approaching the crusher dump. The truck had commenced a right turn at the time of failure. When the suspension failed, the upper portion was driven upwards against the frame member which supports the cab decking. This fractured the cross member and drove it upwards several inches. The lifting of the cab pulled the steering shaft off the splines at the steering box, thus causing a loss of direction control. The driver immediately applied the service brakes but the vehicle's momentum coupled with the loss of steering control, directed it into an impact pile at the crusher dump, which had been placed there for such eventualities. The truck came to rest within a short distance of the top of the pile.

On June 4, 8 and 11 three steering failures occurred because of fractures in the ball stud-tie rod assemblies on three 170-ton haulage vehicles at an open-pit mining operation.

On July 27 the operator of a forklift truck sustained bruise injuries when the forklift he was operating got out of control, ran down an embankment and overturned. The incident was attributed to driver error.

On September 25 a scraper was being used to spread coarse sand at a tailings' dam at an open pit when the right front axle of the scraper broke and thus permitted the right front drive wheel to fall off. It was recommended that annual nondestructive tests be made on such equipment.

On October 20 a failure occurred in the right front spindle of a 120-ton truck. The vehicle was executing a tight turn to the right while traveling at a speed of 5 mph. While the axle spindles are checked for failures on a six-month basis, it was recommended these tests be performed at a greater frequency.

Incidents Experienced During 1977

On January 19 an empty haul truck was being driven back to the lowest bench in an open pit in a direction contrary to the regular traffic pattern. It nearly collided with a loaded truck which was leaving the pit. The empty vehicle jumped a windrow of frozen material at the road verge and ran into the pit sump which contained 1-1/2 metres of water. The driver, bruised, but otherwise unharmed was rescued from the sump in the bucket of a front-end loader. The truck was backed out of the sump and driven to the shop. The operator stated that the steering had locked on him, but no mechanical malfunction could be found during testing at the shop.

On January 25 at a large open-pit coal mine, the right front spindle of a 200-ton truck failed as the vehicle was negotiating a right-hand turn on a dump. The driver estimated that he was traveling at 16 km/h at the time of the failure. Road conditions were good with no rough areas. Routine ultrasonic inspections are carried out at the property every 2000 operating hours.

The above six years of incident/accident data are summarized in Table 5. These data differ significantly from the MSHA-HSAC data in two major respects. First, the British Columbia mine incident/accident reports include many noninjury/nonfatality incidents. The MSHA-HSAC reports do not include accidents not resulting in injury or death. Second, the British Columbia data contain significant numbers of incidents caused by mechanical failure of steering components. These mechanical failures would appear to cause considerable problems for maintenance and production personnel but only small problems in safety areas. The mechanical failures are typically at low speeds and during tight turns. The British Columbia Department of Mines and Petroleum Resources has been active in helping solve these mechanical failure problems. The following excerpt from a letter from Mr. Ray Heistad, a British Columbia mine inspector, discusses the British Columbia approach to this area:

"...our experience has shown that numerous steering system component failures here in British Columbia resulted from either marginal design of mechanical components or poor fabrication of these components. Components such as drag links and tie-rods generally require welding during the

Table 5. Summary of
British Columbia Mine Incidents/Accidents

	Year						Total
	1972	1973	1974	1975	1976	1977	
Steering-related incidents/accidents involving haulage trucks							
Operator error	1	3	2	2	0	1	9
Structural failure	4	0	2	4	8	1	19
Other	0	0	0	0	0	0	0
Steering-related incidents/accidents involving other machines							
Operator error	0	0	0	1	1	0	2
Structural failure	0	0	0	0	1	0	1
Other	0	0	1	0	0	0	1
Total steering-related incidents/accidents	5	3	5	7	10	2	32
Total incidents/accidents reviewed	92	149	220	164	220	171	1016

manufacturing process. In most cases when weld failures occur, it is readily apparent that the weld was inferior — slag inclusions, poor penetration, etc., can usually be observed in these cases. Incidents like this could be controlled by good quality control procedures during manufacture, which should include suitable nondestructive testing of critical components. It is a requirement in British Columbia that the spindles of haulage trucks with a rated gross vehicle weight in excess of 200,000 pounds be subjected to suitable nondestructive tests every 2000 operating hours. This policy was established in 1975 because of in-service fatigue failures of several spindles. The nondestructive test program conducted by one engineering firm during 1975 revealed that 117 of 310 spindles tested were found to be cracked. Although the situation presently is generally much improved, we still receive reports from some mines showing the proportion of cracked spindles to be in the order of 20-25 percent. Several mines have initiated NDT programs of steering linkages scheduled in conjunction with the spindle tests. The ball studs and weld areas of tie-rods and drag links are tested and it is not uncommon to find defects. Generally, ultrasonic is used for spindles and ball studs while magnetic particle is used for welds. This test program has reduced considerably the number of in-service failures of these steering system components."

Mr. Heistad also forwarded representative information on steering system component failures in three British Columbia mines. This information follows:

Steering System Component Failures — Mine A

This large open pit mine operates a fleet of diesel-electric drive haulage trucks. The fleet is comprised of two different models supplied by one manufacturer.

All steering system components of these trucks are routinely checked every 250 operating hours by the P.M. mechanics. At the writer's request, the mine staff consented to review their steering system maintenance records for the period January 1977 to May 1978 for a portion of their haulage fleet. The records of eight of their smaller size trucks having a cumulative total of 39,850 operating hours during the above-noted period and six of their larger size trucks having a cumulative total of 29,350 operating hours during the same period were reviewed. A summary of this review is shown below.

It is apparent that a fairly high number of ball studs are replaced on the trucks. In most cases, however, the ball



stud has not failed but the bushing has. It is this mine's practice to change all components – ball studs, bushing, washer and nut when this occurs. Hydraulic system components such as steering pumps also appear to be replaced fairly frequently. This mine rebuilds the hydraulic components themselves, however they do not as yet have a suitable test bench to check functional integrity after rebuilding. This in turn leads to some premature failures. Contamination has also led to premature failures of components before being detected. During the initial few months exposure to the larger model trucks, various steering system problems which were experienced were partially attributable to lack of formal training of mine maintenance personnel on this type of truck. This problem has now been overcome.

Mine A Steering System Component Failures

	<u>Model 1 (8 Trucks)</u>		<u>Model 2 (6 Trucks)</u>	
	<u>Replaced</u>	<u>Required Maintenance</u>	<u>Replaced</u>	<u>Required Maintenance</u>
<u>Mechanical Linkage Components</u>				
1. Ball studs and bushings	83	25	28	13
2. Tie-rods	1	2	1	2
3. Spindles	5	-	3	1
4. Wheel bearings	4	1	6	-
<u>Hydraulic System Components</u>				
1. Steering pumps	23	-	11	2
2. Steering cylinders	16	11	-	3
3. Steering hoses	8	9	14	19
4. Pressure relief valves	2	28	2	30
5. Steering boxes, valves and linkages	1	-	3	9
6. Emergency steering	3	12	3	44



Steering System Component Failures - Mine B

This mine operates a fleet of two different models and sizes of diesel-electric drive trucks supplied by different manufacturers. A disproportionate number of steering system failures occurred during 1975 and 1976 on one of the models of trucks. A summary of the failures which occurred on 10 of these trucks is shown below. As a result of the experiences at this mine and Mine C, the manufacturer has since redesigned and modified the steering system with a resultant improvement in component reliability. However, we continue to receive the occasional report of in-service failures. Most of these failures have been related back to the loading that the steering systems get when the truck is in a low speed tight turn and the steering is against the stop.

Mine B Steering System Component Failures

	<u>Hours on Part</u>	<u>Remarks</u>
<u>Hydraulic Components</u>		
Steering pump	360	Water in pump
Steering pump	360	Would not hold pressure
Steering pump	1064	No pressure
Steering pump		Failed
Emergency steering pump	672	Pump seized
Steering cylinder	233	End broke off
Steering cylinder	1260	Internal by-passing
Steering cylinder	587	End broke off
Steering cylinder	1290	Blown packing
Steering cylinder	524	End broke off
Steering cylinder	1123	End broke off
Steering cylinder	1675	End broke off
Steering cylinder	1080	End broke off
Steering cylinder	--	End broke off
Steering cylinder	--	End broke off
Steering cylinder	--	End broke off
Steering cylinder	--	End broke off
Steering cylinder	--	End broke off
Steering cylinder	--	End broke off
Orbitral valve	101	Valve by-passed
Orbitral valve	--	Replaced
Orbitral valve	--	Replaced
Orbitral valve	--	Replaced



Mine B Steering System Component Failures (Cont)

<u>Mechanical Components</u>	<u>Hours on Part</u>	<u>Remarks</u>
Ball stud	724	Shank snapped off
Ball stud	1675	Broke
Ball stud	--	Broke
Ball stud	1795	Worn
Ball stud	1311	Worn
Ball stud	342	Worn
Ball stud	321	Worn
Ball stud	1067	Worn
Ball stud	436	Worn
Ball studs (3)	405	Worn
Ball studs (2)	902	Worn
Ball studs (2)	337	Worn
Ball studs (2)	416	Worn
Ball stud	1312	Worn
Ball stud	1123	Worn
Ball stud	--	Worn
Ball stud	--	Worn
Ball stud	--	Worn
L/H bell crank	1865	Socket worn out
Tie-rod end	722	Broke off
Tie-rod end	1225	Broke off
Tie-rod end	693	Broke off
Tie-rod end	803	Broke off
Tie-rod end	662	Broke off
Tie-rod end	560	Broke off
Tie-rod end	--	Broke off
Tie-rod end	--	Broke off
Tie-rod end	--	Broke off
Tie-rod end	--	Broke off
Tie-rods (7)	--	Replaced



Steering System Component Failures – Mine C

This mine has 14 trucks identical to the 10 trucks which experienced steering system problems at Mine B. From November 1975 to December 1976, 45 in-service failures of mechanical components occurred. A summary of these failures is shown below. Again, since the manufacturer modified the steering system, the failure rate of these components has been minimized considerably.

Mine C Steering System Component Failures

<u>Ball Studs</u>	<u>Tie-Rods</u>
1 @ 10 mph loaded	1 @ 5 mph loaded
1 @ 5 mph loaded	1 @ 12 mph loaded
1 @ 7 mph loaded	1 @ 15 mph loaded
1 @ 5 mph loaded	13 @ 5 mph loaded
1 - loaded	
1 @ 10 mph loaded	
1 @ 3 mph loaded	2 @ 10 mph loaded
1 @ 5 mph loaded	4 loaded, speed unknown
1 @ 18 mph loaded straight	
1 @ 16 mph loaded straight	2 @ 5 mph empty
	1 @ 5 mph empty – straight
1 @ 15 mph empty straight	1 @ 8 mph empty
1 @ 15 mph empty turning	1 @ 10 mph empty
1 @ 5 mph empty straight	1 @ 3 mph empty
1 @ 3 mph empty	1 empty, speed unknown
1 @ 2 mph empty	
1 @ 5 mph empty	

Conversations with mine safety officials in Alberta indicate similar concern on the potential structural deficiencies of some steering system components.

During the performance period of this study (late 1977 through 1978) Woodward Associates, Inc. personnel discussed steering system reliability, maintenance procedures, and accident experience with U.S. mine personnel. These discussions were sometimes secondary to the primary purpose of the mine visit. These mine personnel were not able to identify any design deficiencies of steering systems that produced safety problems. There were a few complaints about the service received from some equipment manufacturers or component



suppliers. There were discussions on the inadequacy of equipment operator training and the resultant machine damage caused by inexperienced, poorly trained operators. There were several suggestions for simplifying the maintenance procedures and for increasing reliability; these comments were not safety-oriented. It appeared that the mining personnel view steering systems in modern machines as safe although certainly not without operational problems.

The above accident and incident information supports a conclusion that the steering systems used on surface mining machines are not a significant factor in causing injury and death to mine personnel. Though the safety performance of today's steering systems is satisfactory, the information reviewed suggests that improvements in structural design, fabrication, and quality control of steering system mechanical components would help reduce equipment downtime for repairs and maintenance.

The steering-related accidents and incidents can be examined to attempt to determine the causative factors. It is realized that accidents may be caused by more than one precipitating factor. The list given below states the factors that, either singly or in combination with others, contribute to the accidents reviewed.

The list given below does not include "loss of control" as a causative factor. The reason the operator has "lost control" of the machine is one of the factors listed below.

- Operator inexperience with a specific unusual situation.
- Operator not adequately trained for routine or expected situations.
- Operator inattentiveness, carelessness, or lack of alertness.

- Mechanical failure of a steering system component.
- Loss of power from machine engine (usually a result of inadequate operator training).
- Operator did not follow established vehicle operational procedure.
- Hydraulic failure of a steering system component.
- Emergency steering system nonfunctional.

The above accident causative factors may, in some cases, be directly related to poor maintenance practices, to incomplete or nonexistent training programs, to poor equipment design, to inadequate employee rest periods or to extended work hours of employees.

Of the 13 steering-related accidents in U.S. mines and the 32 incidents/accidents in British Columbia mines, 10 of the U.S. accidents and 9 of the British Columbia incidents seem to be caused by some form of operator error. Increased training of the equipment operators may be the most productive approach to reducing these types of accidents. For the remaining accidents, emergency steering capability (for engine stall situations) would seem to help considerably.

From observations made during this study and during other mine accident investigation activities, Woodward Associates, Inc. has developed opinions on the type of training that should be given to equipment operators. It is believed that an important goal of equipment operator training is to give the trainee knowledge and experience on how to handle emergency or abnormal operating conditions. Examination of accident reports indicates that a high percentage of accidents leading to injury or death are the result of the operator

initiating an action that causes the normal routine operation of the machine to be altered. The machine is now not operating normally. The operator may have stalled the engine, sped downhill too fast, fallen asleep, etc., or have incorrectly performed the operation of the machine. Proper training of the equipment operator would include procedures on "how to get out of trouble" as well as how to perform the routine machine operation. Table 6 lists the desirable elements of an equipment operator training program.

Table 6. Equipment Operator Training Program

Element	General Title	Training Objectives	Machine Coverage
1	Personal Protection	Induce trainee to wear proper working apparel, use safety equipment correctly (hard hats, safety glasses, ear plugs, etc.) and especially to inspect installed protective structures and to use seat belts continuously.	All mobile machines requiring operators.
2	Pre-Shift Inspection	Induce trainee to conduct an effective safety check of his machine before operating it. Includes overall inspection of machine and checks of gauges, brakes and steering, etc.	Generic type specific.
3	Machine Systems, Features and Normal Operating Procedures	Understanding by trainee of characteristics of his machine, how the systems function, how to operate it to achieve maximum productivity safely. Practice in normal operation.	Model specific.
4	Emergency or Abnormal Machine Operations	Understanding by trainee of proper actions to be taken under abnormal conditions (failure of machine system or component, loss of traction, loss of control, ground movement, etc.). Practice in abnormal operations.	Model specific.
5	Proficiency Demonstration	One-on-one instruction of trainee followed by opportunity for trainee to demonstrate knowledge and proficiency relative to objectives in Elements 1 through 4.	Model specific.

SECTION 5.0

TECHNICAL EVALUATION GROUP ACTIVITIES

During meetings between the Bureau of Mines and Woodward Associates, Inc. held prior to initiation of this study the value of including a provision for soliciting industry technical review and comment was discussed. It was decided that the benefits accrued to this study would be worth the time and expense of organizing a group of technical representatives from the mining and mining equipment industry.

5.1 TECHNICAL EVALUATION GROUP MEETING NO. 1

The Technical Evaluation Group participants were selected from manufacturer's engineering and product safety departments, from industry and technical associations, from U.S. and Canadian government agencies, from selected research organizations and from mining companies. This carefully selected group of individuals represented various interests and viewpoints on the steering systems used in rubber-tired mobile surface mining equipment. Attendees at the first Technical Evaluation Group (TEG) meeting are listed below:

James Ault	Bureau of Mines Pittsburgh, PA
Lanson Becker	Hydreco Kalamazoo, MI
James Carr	Caterpillar Tractor Co. Peoria, IL
Richard Evans	Unit Rig and Equipment Co. Tulsa, OK
George Fisher	Terex Division - GM Hudson, OH
Dr. Ernest Fitch	Oklahoma State University Stillwater, OK



James Fraser	Mine Safety and Health Administration Reno, NV
Thomas Goodney	John Deere Dubuque Works Dubuque, IA
Leslie Hajdo	University of Calgary Alberta, Canada
Kenneth Hammond	Peabody Coal Company St. Charles, MO
Ray Heistad	Department of Mine and Petroleum Resources Kamloops, B.C.
Roy Jameson	Mine Safety and Health Administration Denver, CO
Guy Johnson	Bureau of Mines Twin Cities, MN
Joseph Judeikis	Mine Safety and Health Administration Triadelphia, WV
Paul Kelsey	Marathon LeTourneau Company Longview, TX
Bernard Larson	Eaton Corporation Eden Prairie, MN
Peter Maté	Woodward Associates, Inc. San Diego, CA
Robert McCracken	Woodward Associates, Inc. San Diego, CA
William Miller	CIMA Milwaukee, WI
Manny Naft	Euclid, Inc. Euclid, OH
Bruce Nelson	Bureau of Mines Twin Cities, MN
Thomas Ritter	Southwest Research Institute San Antonio, TX
Ronald Rumpf	WABCO Peoria, IL
Louis Schaffer	Woodward Associates, Inc. Genoa, NV
Bill Schroeder	International Harvester Chicago, IL



Peter Seabase	National Machine Company Stow, OH
Terry Smith	Department of Labour Occupational Health and Safety Division Mines Branch Calgary, Alberta, Canada
Edwin Thomasson	Mine Safety and Health Administration Arlington, VA
Jack Woodward	Woodward Associates, Inc. San Diego, CA
Henry Zitko	Workers' Compensation Board Vancouver, B.C.

A copy of a report describing the material gathered during the first six months of this project (Phase I) was sent to each TEG member to provide background on the project and for review and comment by the prospective attendee. This Phase I report contained much of the information included in other sections of this Program Final Report. Attendees were asked to "mark-up" these copies with suggested changes, areas of disagreement, etc., and bring their copy to the first TEG meeting. This Program Final Report reflects many of the changes suggested by the TEG members.

The agenda for the first meeting of the USBM Steering System Technical Evaluation Group was as follows:

TEG Meeting – First Day

9:00 a.m.	Introduction of TEG Attendees Review of Purposes/Objectives of TEG Meeting
10:00 a.m.	Review of Phase I of USBM Project Entitled "Steering System Survey for Surface Mining Equipment" – Robert McCracken
12:00 noon	Lunch



- 1:15 p.m. Review of SAE Recommended Practice XJ53, "Minimum Performance Criteria for Emergency Steering of Wheeled Earth-moving Construction Machines" – Ronald Rumpf
- 2:00 p.m. The Requirement for Operator Training in Surface Mines – Louis Schaffer
- 2:45 p.m. The Importance of Contamination Control in Hydraulic Systems – Dr. Ernest Fitch
- 3:45 p.m. Open Discussion on Following Topics:
- Potential Advances in the State-of-the Art of Steering Systems
 - Steering System Reliability Approaches
 - Product Liability
- 5:15 p.m. Review of Day's Activities/Adjourn

TEG Meeting – Second Day

- 9:00 a.m. Group Discussion on Following Topics:
- Is there a need for MSHA regulations covering primary and emergency steering systems?
 - Is there a need for performance standards on steering systems? On components?
- 10:30 a.m. Discussion of the Purpose/Objectives of the Next TEG Meeting
- 12:00 noon Lunch/Adjourn

The members of the TEG were active in their comments on the contents of the Phase I report. Though some comments reflected individual or company bias toward or against specific steering system approaches, a high percentage of the comments were useful to this project. The Phase I reports that were returned to WAI by the attendees were each studied to help guide the preparation of the agenda for TEG Meeting No. 2 and to correct or clarify portions of the Phase I report that were intended for use in this Program Final Report.



The discussion during TEG Meeting No. 1 covered the following areas:

1. Steering System-Related Accidents. In addition to reviewing the Mine Safety and Health Administration accident records and British Columbia incident/accident information (material similar to that discussed at the TEG meeting is contained in Section 4.0, "Steering-Related Accident Information"), TEG members were asked to comment on their knowledge of steering-related accidents. Mr. Ray Heistad affirmed the British Columbia data and indicated that the frequency of structural failure of steering system mechanical parts on haulage trucks was much higher than evident from the data presented by WAI. He promised to supply additional failure information. Mr. Terry Smith reported similar structural failures in Alberta mines. Several representatives of the haulage truck manufacturers involved in these Canadian mine steering component failures acknowledged these incidents and pointed out that these failures were not resulting in injuries or deaths and, therefore, were not a serious safety problem. The mining environment (weather, condition of haul roads, etc.) is very harsh in Canadian mines and the frequency of structural failures may be greater than in United States mines. Generally, these structural failures have occurred at low speeds during maneuvering. This situation produces high stresses on structural components. Some of these structural failures were being experienced on new haulage truck models recently introduced into Canadian mine service. Some

failures appear to be due to improper manufacturing procedures. An opinion developed (not shared by all TEG members) that this type of structural failure does not represent a serious safety problem and should be considered as either a maintenance or quality control problem and resolved between the equipment owner and the equipment supplier.

Though there appears to be some evidence (chiefly hearsay) that there have been infrequent problems with hydraulic components of steering systems ("sticky" spool valves, hose ruptures, valve malfunctions, damaged cylinders, etc.), no instances where hydraulic malfunctions or failures had caused an injury or fatality accident could be recalled by the TEG members. The group consensus seemed to be that the steering systems in use today are reliable if maintained properly.

Since three of the four fatalities recorded in the MSHA accident records studied involved front-end loaders, the question of "inherent" instability (especially when trammed backwards) of front-end loaders at high speeds was discussed. The front-end loader steering performance objectives may be the most difficult for the designer to accomplish. The machine must be highly maneuverable at low speeds to perform its work and yet be relatively insensitive to the operator's manual inputs at higher speeds. These performance objectives are in conflict and no simple solution is available. Some mine operations forbid high speed travel

with front-end loaders; some even going to the trouble to "lock out" the higher gear capabilities through plates on the transmission gear selector. There is some concern among equipment manufacturers that attempts to provide solutions to this problem through sophisticated designs may introduce new, and more serious, safety problems. Proper equipment operator training and discipline are the most straightforward approaches to reducing this hazard.

2. Supplementary/Auxiliary/Emergency Steering Capability. One of the causes of steering-related accidents is the improper operation of a machine leading to a stalled engine. In machines having hydrostatic steering, there is no way to provide steering forces when the hydraulic system is not operating. The operation of the hydraulic system depends upon the machine's engine for power. In a stalled engine situation, the machine operator is unable to perform steering maneuvers and an accident may result. The machine operator should attempt to stop the machine by braking if the engine stalls, however, the loss of steering may bring on panic and possibly cause the operator to take no action. Since adequate machine operator training is unlikely for all machine operators in all mine operations, the capability to perform some minimal steering after an engine stall is desirable. It is important that this emergency steering capability be automatic (does not require machine operator action) and that a warning (audible or visual signal; preferably

both) be given to the machine operator that the emergency steering system is operating. The operator should, at the earliest safe opportunity, bring the machine to a stop. The desirability of an automatic emergency steering capability has been recognized by the equipment manufacturers. Through the Society of Automotive Engineers, Inc. (SAE), technical experts have conducted a voluntary cooperative effort to develop performance criteria for emergency steering systems. A draft of this document, entitled "Minimum Performance Criteria for Emergency Steering of Wheeled Earthmoving Construction Machines," was reviewed by the TEG members. This document, which will be designated SAE Recommended Practice J53 when published by SAE, was presented to the TEG members by Mr. Ronald Rumpf, the Chairman of the SAE Ad Hoc Committee on Emergency Steering. Mr. Rumpf reviewed the extensive field testing, technical interchange meetings, and standard preparation activities that have preceded the drafting of this document. This SAE Recommended Practice (this document is included with this report as Appendix A) defines a test course and test procedure for assuring that a level of minimum steering performance is attained by the machine during emergency conditions. This performance standard satisfies the emergency steering need identified in the review of the accident records.

3. Accident Investigation Procedures. Review of the British Columbia incident/accident records



has been especially useful. Since the British Columbia data contain descriptions of accidents that did not result in injury or death (but could have under different circumstances) there are more individual incidents to study. This larger number of incidents per machine population supports statements made by Mr. Louis Schaffer on the "accident pyramid" phenomenon. Mr. Schaffer reviewed the relationship between fatality accidents, injury accidents, and accidents producing no injury. Mr. Schaffer defined an accident as "an event, other than a deliberate stop, which is unexpected and which interrupts normal work of the man-machine work unit." Information was presented that suggests that in the surface mining industry for every major injury accident there are approximately 64 minor injury accidents and approximately 475 accidents with no injury. This compares with an United States "all industry" accident pyramid of 29 minor injury accidents and 300 no injury accidents for every major injury. The suggestion is made that information on all accidents, whether they cause injuries or not, is useful in reducing potential injury accidents. Mr. Schaffer also pointed out that many of the no injury accidents cause equipment damage, lost production time, and schedule delays. The British Columbia incident reports serve to alert mining operations of potential accident situations that could result in personnel injury or production interruptions.



The need for accurate accident reporting was also discussed at TEG Meeting No. 1. The group concurred that in accidents involving equipment of the types studied on this project, valuable technical information could be gained by the presence of a qualified technical representative of the equipment manufacturer during the accident investigation. It is recognized that this is not practical in every accident. However, MSHA investigates every fatal accident occurring in United States mines. A fairly detailed report is prepared and is used by the MSHA Health and Safety Analysis Center and by Bureau of Mines study contractors in efforts to reduce mining accidents. The usefulness of these reports is significantly enhanced if the causative factors are carefully identified. A definitive description of the equipment malfunction (if any), the operator actions, the operating environment, etc., will aid the safety engineer. The TEG members supported a recommendation that MSHA invite qualified technical representatives to participate in accident investigations involving mobile equipment.

4. Steering System Reliability Assessment. After considerable discussion, the TEG members agreed that it is not possible to agree on relative reliability ratings for the different generic types of steering systems. Individual component reliabilities have large influences on subsystem reliabilities and on the system reliability. Attempts to assign reliability figures to components or systems will be misleading unless the specific operating conditions and

hydraulic fluid contaminants are known. The variables affecting reliability are broader than any inherent reliability of any of the steering systems.

A general concern was stated about dual or redundant steering system reliability. It was stated that the overall system reliability might be compromised unless very careful attention is given to the design philosophy and unless a very careful analysis of failure effects is conducted. More sophisticated designs are not necessarily more reliable.

5. Contamination Control in Hydraulic Systems.

Dr. Ernest Fitch presented a summary of the extensive studies conducted at the Fluid Power Research Institute, Oklahoma State University, on the effects of contaminants on hydraulic system performance and on methods used to determine contaminant characteristics. This effort has led to the preparation of performance and test standards used in military and commercial hydraulic component evaluations.

Of considerable concern to the TEG members is the possible deleterious effects of the various "fire resistant fluids" being introduced in hydraulic systems. Dr. Fitch's group is active in this area. The TEG members suggested continued work in this field that is oriented toward the hydraulic systems used in mining and construction machines.

6. Potential Advances in the State-of-the-Technology of Steering Systems.

The past two decades have produced significant advances

in steering system technology. While there may be future "breakthroughs" in the steering system approaches through application of technology emerging in other technical and scientific fields, it is difficult to anticipate or schedule these "breakthroughs." The TEG members were unable to identify any major new advances on the technical horizon. In the near term, advances will be made in the efficiency, reliability, maintainability, and sensitivity of components used in steering systems. No departure from hydraulic systems is anticipated.

Members of the TEG were asked to prepare suggestions on possible Bureau of Mines-sponsored research on steering systems for discussion at the next TEG meeting.

7. Preliminary Conclusions and Recommendations.

Woodward Associates, Inc. personnel presented sets of preliminary conclusions and recommendations (Figure 50 and Figure 51) that had been prepared from information developed during the first six months (Phase I) of this study.

The TEG members were asked to comment on each of the preliminary conclusions and recommendations and to offer changes or modifications with rationale or justification for any differences. Each of the preliminary conclusions

- TODAY'S STATE-OF-THE-TECHNOLOGY IS PRODUCING RELIABLE STEERING SYSTEMS.
- ADVANCES IN STEERING SYSTEMS RELIABILITY WILL NOT PRODUCE LARGE REDUCTIONS IN SURFACE MINE FATALITY/INJURY ACCIDENT RATES.
- ADVANCES IN STEERING SYSTEM TECHNOLOGY AND RELIABILITY WILL BENEFIT MINES IN MAINTENANCE REQUIREMENTS AND IN MACHINE AVAILABILITY.
- EQUIPMENT OPERATOR TRAINING AND OPERATOR DISCIPLINE HAVE POTENTIAL TO PRODUCE SIGNIFICANT REDUCTIONS IN FATALITY/INJURY RATES.
- STEERING CAPABILITY DURING "ENGINE-OFF" SITUATION DESIRABLE.

Figure 50. Preliminary Conclusions Presented at TEG Meeting No. 1

is discussed below with the TEG reaction/comment.

- Today's state-of-the-technology is producing reliable steering systems.

This conclusion is valid if maintenance and repair are not considered in the reliability assessment and safety considerations are the sole concern. It is suggested that maintenance and repair



PRELIMINARY RECOMMENDATIONS

BUREAU OF MINES SPONSOR RESEARCH IN FOLLOWING AREAS:

- DEMONSTRATION OF ADVANCED COMPONENT TECHNOLOGY DIRECTED TOWARD HIGH RELIABILITY AND LOW MAINTENANCE.
- PREPARATION OF MATERIAL TO BE USED IN TRAINING EQUIPMENT OPERATORS TO HANDLE EMERGENCY SITUATIONS.
- INVESTIGATION OF POSSIBLE SOLUTIONS TO THE PECULIAR STEERING REQUIREMENTS OF FRONT-END LOADERS.

MINE SAFETY AND HEALTH ADMINISTRATION CONSIDER THE FOLLOWING:

- A REGULATION REQUIRING AN "AUTOMATIC" EMERGENCY STEERING CAPABILITY IN EVENT OF PRIMARY ENGINE FAILURE. USE SAE XJ53 PERFORMANCE GUIDELINE.
- INCLUDING EMERGENCY SITUATION TRAINING AS PART OF THE EQUIPMENT OPERATOR TRAINING NOW REQUIRED.

Figure 51. Preliminary Recommendations
Presented at TEG Meeting No. 1



reliability problems that do not represent potential safety concerns and are best left to the equipment owner and the equipment manufacturer. The competitive marketplace is a great influence in areas of maintenance and repair.

- Advances in steering system reliability will not produce large reductions in surface mine fatality/injury accident rates. Steering system-related accidents that produce injuries or deaths are infrequent and, in comparison with other causes of mobile equipment accidents, are almost insignificant. The steering system-related accidents that do occur may not be reduced through improved steering system reliability. Other approaches to reducing these accidents would probably be more successful.
- Advances in steering system technology and reliability will benefit mines in maintenance requirements and in machine availability. The potential for increasing the machine productivity and reducing maintenance costs is attractive to the mine operators. Steering systems are not considered to require unusually high maintenance by mines. The gains to be realized through technology and reliability advances would be important if they signal comparable improvements in the hydraulic systems in general. The area of seal maintenance and replacement was suggested as a fruitful area for improvement.



- Equipment operator training and operator discipline have the potential to produce significant reductions in fatality/injury rates.

This conclusion was unanimously accepted by the TEG members. It was emphasized by members that this conclusion assumes the development and use of effective training approaches and assumes that operator discipline approaches will be acceptable to both the union and company management. Comments were made on the desirability of good maintenance training and its potential benefits.

- Steering capability during "engine-off" situation is desirable.

There was substantial agreement among TEG members that this conclusion is valid. Some members commented that the proper operator training would reduce the need for emergency steering capability. Some members expressed opinions that the need for emergency steering capability was only on specific types of mobile equipment. There was general agreement that some slower speed machines did not need emergency steering. The SAE Recommended Practice J53 will be applicable to machines having maximum rated speeds in excess of 20 km/h (12.4 mph).

In summary, there was little disagreement from the TEG members on the preliminary conclusions

presented at TEG Meeting No. 1. An additional conclusion was suggested by TEG members. It is as follows:

- The accident records at the MSHA-HSAC offices and available from British Columbia are extremely useful for placing equipment safety research in perspective. The TEG members expressed their compliments to the Bureau of Mines for doing the proper homework prior to suggesting the promulgation of new MSHA regulations. The use of historical accident records to help justify the need for future safety research or for background in preparing regulations adds to the credibility of Bureau or MSHA actions. It was stated that the accident records presented were good justification for the present requirements for rollover protective structures on mobile equipment.

Woodward Associates, Inc. personnel presented preliminary recommendations for Bureau of Mines action and for MSHA action. The reaction/comments from the TEG members are summarized below. The recommendations to the Bureau of Mines are given first.

- Sponsor research toward demonstration of advanced component technology directed toward high reliability and low maintenance. This recommendation received a mixed response from TEG members. Reaction varied from "keep the government out

of equipment development" to ready acceptance of the need for the Bureau to stimulate or catalyze the development of advanced steering systems. Some conversations covered problems with proprietary rights and patent rights. The reluctance of some component suppliers and equipment manufacturers to participate in government-funded research and development was stated.

It was decided that TEG members would address this area of activity during the time between TEG Meeting No. 1 and Meeting No. 2 and be prepared to suggest specific technology areas for Bureau sponsorship.

- Sponsor the preparation of material to be used in training equipment operators to handle emergency situations.

The TEG members concurred with this recommendation. There was an expression of concern about the product liability implications of a component supplier or an equipment manufacturer supplying information that acknowledge potential failure or malfunction of their product. A comment was made to the effect that "plaintiff attorneys could misuse statements about the need to train equipment operators to handle emergency situations."

- Sponsor the investigation of possible solutions to the peculiar steering requirements of front-end loaders.

There was not agreement among TEG members that the front-end loader has "peculiar steering requirements." In any event, the engineering personnel at the equipment manufacturers are working continually toward safer operating machines. The TEG members did not have confidence that study contractors working for the Bureau of Mines would be successful in developing engineering solutions to basic equipment design problems in advance of developments within the equipment manufacturing industry. This recommendation was abandoned.

Recommendations for the Mine Safety and Health Administration and TEG member comments are given below:

- Consider a regulation requiring an "automatic" emergency steering capability in the event of a primary engine failure. Use SAE J53 as a performance guideline.

The reaction to this recommendation was mixed. British Columbia and Alberta have regulations requiring emergency steering on mining equipment. These regulations are reproduced below:

British Columbia Mines Regulation Act

"Rule 266. (a) Unless otherwise approved by the Inspector, where air brakes are used they shall be installed and maintained

according to the rules under the *Industrial Transportation Act*.

(b) Where any rubber-tired motor-vehicle depends upon power for steering and where the loss of such power might prevent the vehicle from being steered manually, an auxiliary device shall be installed that would enable the driver to steer the vehicle for a sufficient time to bring it to a safe stop."

British Columbia Coal Mines Regulation Act

"Rule 198. (a) Unless otherwise approved by the inspector, where air brakes are used they shall be installed and maintained according to the rules under the *Industrial Transportation Act*.

(b) Where any rubber-tired motor-vehicle depends upon power for steering and where the loss of such power may prevent the vehicle from being steered manually, an auxiliary device shall be installed to enable the driver to steer the vehicle for a sufficient period of time to bring it to a safe stop."

Alberta Coal Mines Safety Regulations

"Steering and Emergency Steering on Equipment.

99. (1) Where equipment fitted with power or power-assisted steering cannot be readily steered manually in the event of failure of the power source, an emergency-steering arrangement shall be provided that shall

- (a) ensure adequate steering control for the equipment to be brought to rest by the braking system after the power failure has occurred,
- (b) come into use automatically upon failure of the power source, and
- (c) operate a visible warning device to alert the driver that the steering power or power assistance is not available and that emergency steering is in use.

(2) Where equipment is dependent entirely on fluid pressure for normal steering, with no mechanical linkage between the steering wheel



and the road wheels, the equipment shall be provided with

- (a) a divided or dual steering system to ensure that any component failure resulting in a loss of fluid pressure in one part of the system would leave sufficient steering capacity in the unaffected circuit for the equipment to be brought to a safe stop, and
 - (b) a warning system to alert the driver that one part of the steering system has failed.
- (3) Hoses used in hydraulic steering circuits shall have a bursting strength safety factor of not less than four in relation to the highest design pressure of the circuit."

These regulations were promulgated in response to a perceived need to provide such capability on mobile mining equipment. Members of the TEG from Canada are satisfied that these regulations are valid and are providing a safer work environment in the mines of these two provinces.

An emergency steering system meeting the performance requirements of SAE Recommended Practice J53 would probably satisfy the British Columbia regulations but would not satisfy paragraph (2) of the Alberta regulation.

The TEG members engaged in spirited discussion on the merits of voluntary consensus standards and the potential negative effects of mandatory government regulations. A general position evolved that questioned the need for a mandatory regulation when the accident data appeared to indicate that steering-related accidents were minimal in comparison with other mobile equipment accident causative

factors. Equipment manufacturer's representatives stated that many machine models now being produced have automatic emergency steering capability consistent with SAE Recommended Practice J53 requirements as standard equipment and that emergency steering is available as an option on many of the machine models not so equipped. The TEG members agreed that it is desirable to have the mine operator made more aware of the potential value of emergency steering. The mine purchasing office could use SAE Recommended Practice J53 in their equipment specification to assure comparable systems are being proposed.

This recommendation was modified to suggest that MSHA help educate the mine operators on the types of steering-related accidents that have occurred and on the availability of emergency steering systems on new machines. The majority of the TEG members were strongly against any consideration of in-mine retrofit of emergency steering on machines in the field.

- Include emergency situation training as part of the equipment operator training now required.

Section 115 of the Federal Mine Safety and Health Act of 1977 requires training of miners. As part of the new task training of equipment operators, MSHA could include emergency situation training. The TEG members concurred in this recommendation.

In addition to the above recommendations to MSHA, the TEG members suggested the following:

- Consider a general upgrading of the causal information contained in mine accident reports. Include representatives from equipment manufacturers as part of the accident investigation team. Stress accurate identification of the machine involved. Stress identification of primary and contributory causes of accidents.

All TEG members were of the opinion that accident data review is beneficial in helping solve equipment safety problems. The accident reports received from the field should be as accurate as possible; participation by a technical representative of the equipment manufacturer should help attain improved accuracy.

Some members of the TEG felt MSHA should initiate an incident reporting system similar to the British Columbia system.

The first TEG meeting ended with requests to TEG members to take the following actions:

1. Forward steering-related accident data to WAI.
2. Suggest potential approaches to advancing steering system reliability and maintainability.
3. Comment on the need for MSHA regulations covering steering system performance.

5.2 TECHNICAL EVALUATION GROUP MEETING NO. 2

Review of the activities and accomplishments of TEG Meeting No. 1 confirmed the benefit of an organized technical interchange meeting between the various elements of the mining industry. It was decided that additional representation from mining companies was desirable, therefore four representatives from coal and non-coal mines were invited to TEG Meeting No. 2. Since some discussion during TEG Meeting No. 1 had addressed equipment operator training and its acceptance by organized labor, it was decided to invite Mr. Jack Short of Operating Engineers Union Local No. 3 to participate in TEG Meeting No. 2 and to review the union's training activities at the Rancho Murieta Training Center in California.

New members of the Technical Evaluation Group were asked to meet with WAI personnel on the day prior to the second TEG meeting to review the activities leading up to TEG Meeting No. 2.

The attendees at the second Technical Evaluation Group meeting are listed below:

Lanson Becker	Hydreco Kalamazoo, MI
James Carr	Caterpillar Tractor Co. Peoria, IL
Ray Chavez	Arch Minerals Corporation Seminole Mine No. 2 Hanna, WY
Richard Evans	Unit Rig and Equipment Co. Tulsa, OK
Cliff Farmer	Woodward Associates, Inc. Utah Operations Office St. George, UT
Eduardo Ferreras	Woodward Associates, Inc. San Diego, CA
George Fisher	Terex Division - GM Hudson, OH



Dr. Ernest Fitch	Fluid Power Research Center Oklahoma State University Stillwater, OK
James Frazer	Mine Safety and Health Administration Reno, NV
Thomas Goodney	John Deere Dubuque Works Dubuque, IA
Kenneth Hammond	Peabody Coal Company St. Charles, MO
Gary Hayes	Anaconda Company Berkeley Pit Garage Butte, MT
Ray Heistad	Department of Mines and Petroleum Kamloops, B.C.
Guy Johnson	Bureau of Mines Minneapolis, MN
Michael Kepple	Minntac Mine, U.S. Steel Mt. Iron, MN
Bernard Larson	Eaton Corporation Eden Prairie, MN
Robert McCracken	Woodward Associates, Inc. San Diego, CA
Michael McGuire	Mine Safety and Health Administration Denver, CO
John Megenhardt	AMAX Coal Co. Evansville, IN
William Miller	CIMA Milwaukee, WI
Manny Naft	Euclid, Inc. Euclid, OH
Bruce Nelson	Bureau of Mines Minneapolis, MN
Bill Noble	Bureau of Mines Spokane, WA
Pete Piglia	National Machine Company Stow, OH
Thomas Ritter	Southwest Research Institute San Antonio, TX



Ronald Rumpf	WABCO Peoria, IL
William Schroeder	International Harvester Company Libertyville, IL
Peter Seabase	National Machine Company Stow, OH
Jack Short	Operating Engineer's Union No. 3 Sacramento, CA
Edwin Thomasson	Mine Safety and Health Administration Arlington, VA
Jack Woodward	Woodward Associates, Inc. San Diego, CA
Henry Zitko	Workers' Compensation Board of British Columbia Vancouver, B.C.

The agenda for the second TEG meeting was as follows:

TEG Meeting – First Day

9:00 a.m.	Review Discussion on Implications of Accident Data
12:00 noon	Lunch
1:00 p.m.	Review of Proposed USBM Activities
5:30 p.m.	Adjourn

TEG Meeting – Second Day

9:00 a.m.	Review of Recommendations to MSHA
12:00 noon	Lunch/adjourn

Several meeting attendees had written letters to WAI during the period between TEG meetings. These letters commented on the value of these meetings and offered pertinent data and opinions. The contents of these letters were discussed at appropriate times during this TEG meeting and are included in the recap of the TEG activities given below.

The following general areas were discussed during the second TEG meeting:

1. Additional Steering System-Related Accidents.

Mr. Henry Zitko reported on two interesting steering-related accidents reported during the last two years to the Workers' Compensation Board of British Columbia. This first involved the driver of a loaded log transporter. The driver had previous experience on mine haul trucks and had only one successful instructional round trip on this truck prior to the accident. He was descending a 5 percent grade alone on a slowly tightening curve. For some reason, he killed the engine, lost steering, and could not stay on the changing curved road. He was killed when the truck left the road. An emergency steering capability may have allowed the driver to successfully negotiate the curved road.

The second accident involved a steering arm failure on a log transporter. Investigation by WCB engineers and by the manufacturer indicated that the failure was due to fatigue. Subsequent annual nondestructive testing on the steering arms of this fleet of trucks resulted in about 40 percent replacement. This leads to a serious questioning as to whether adequate factors of safety or correct design criteria were used on these steering arms. Emergency steering capability, as defined in SAE Recommended Practice J53, would not have prevented this accident. A reassessment of the design practices, and

perhaps of manufacturing procedures, is necessary to help reduce this type of accident.

Mr. Zitko also commented on the probability that some accidents reported as rollovers should be included in the steering-related accident category. The fact that a steering failure initiated the rollover is not presented (or even known) by the accident investigator in many instances.

Mr. Ray Heistad provided steering system component failure information received from three mines in British Columbia. This material is presented on pages 120 to 126 of this report.

Representatives of mining companies confirmed the statements made during TEG Meeting No. 1 on the "accident pyramid." These mines experience high numbers of "work interruptions" due to noninjury or "nonreportable injury" accidents.

2. Emergency Steering Systems. Mr. Henry Zitko commented on the British Columbia Workers' Compensation Board concern about the reliability of battery-powered emergency steering systems in areas experiencing adverse weather conditions. Reports coming into WCB indicate a majority of electrically driven emergency steering systems on mobile equipment in British Columbia do not function. An emergency steering performance requirement like SAE Recommended Practice J53 may not be valid for low temperature conditions unless the testing is conducted at low temperatures or unless the system is degraded to reflect winter conditions. The WCB is inclined to not

accept battery-powered emergency steering systems unless reasonable tests were conducted simulating the adverse operating conditions.

Mr. Gary Hayes, speaking from experience gained in mines near Butte, Montana, wrote:

"Electric emergency steering, with the open centered system, has proven itself to be very trouble-free, reliable and safe."

On the subject of testing emergency steering systems in the field, Mr. Ray Heistad wrote the following:

"The concensus of most of those present at the (TEG) meeting indicated that functional verification tests of wheel-driven emergency steering systems was dangerous. As a field inspector, I have on many occasions directed equipment operators to check the operation of their vehicles' wheel-driven pumps. Generally one of two procedures have been used. One method is by accelerating up to approximately 10 or 12 mph in an isolated section of the pit floor and then shutting the engine down and while coasting, checking the steering ability of the unit. The other method used is starting the test near the bottom of a haulage ramp (usually the ramp leading on to the pit floor), and while coasting, ensure maneuverability. Of course, the braking system integrity of the vehicles are thoroughly checked to ensure the vehicle can be quickly stopped should the need arise. While these relatively "primitive" tests may not expose all potential deficiencies which may be present in wheel-driven back-up steering systems, they can give some indication as to their performance capabilities."

3. Training of Equipment Operators. Mr. Jack Short discussed the construction equipment operator training that is being conducted by Operating Engineers Local No. 3 at their Rancho Murieta Training Center near Sacramento, California. Mr. Short emphasized the Operating Engineers'



goal of providing "high quality productive operators to the construction industry." The following material was excerpted from information presented by Mr. Short:

"The Probation/Orientation Period of Apprenticeship consists of ten weeks of training covering the gamut of what the newcomer must know to make it in the industry.

The first week is orientation to the construction industry with particular emphasis on the work of an operating engineer. During this week the first aid course is taken.

The second week is all gradechecking. The schedule then breaks down into training days on specific equipment. The attempt is to spend as much time as needed for a machine without overextending the time to the expense of other machines. Consequently the concept of training by days rather than by weeks.

In addition to gradechecking, first aid, driver's training with a trip to the DMV, the CEO apprentice will learn some welding, lubrication techniques, the heavy duty mechanic functions and get one on one instruction and seat time on eleven different pieces of equipment and the operation of rock, sand and gravel and mixing plants.

The newly indentured apprentices will enter the Probation/Orientation Period with overlapping classes, the schedule is designed to get all the apprentices estimated to be needed by the industry out of the program during the peak work season. The unique scheduling permits expanding or shrinking the program in response to the general work picture."

Mr. Short also provided a list of the 59 pieces of equipment in use for training purposes at Rancho Murieta. Equipment includes dozers, compactors, motor graders, scrapers, backhoes, cranes, draglines, loaders, and trenchers.

On the subject of operator safety, Mr. Short stated that the Operating Engineers Local No. 3



often sides with the construction contractor in disputes over operator safety discipline. He cited the union's strict position on the need for rollover protective structures and seat belts and the requirement that the operator wear the seat belt.

Mr. Ray Heistad wrote:

"We agree with the suggestion that better trained and qualified operators would probably contribute a great deal to reducing accidents involving mobile equipment. Recently, a limited analysis of accidents covering a two year period in British Columbia mines revealed that of 45 accidents involving vehicles (mostly loss of control), 26 of the operators had less than six months experience. Accident investigations have in many cases pointed out training program shortcomings, particularly with respect to emergency procedures. We have also found that it is not uncommon for operators to be unaware of equipment modifications which can affect the safe operation of vehicles. It is not sufficient to train operators just to drive their machines, they must understand how and why the various control functions operate and the limitations of their equipment. Many mines are now including some form of "comprehension" training in their programs. In some cases, this could involve the trainee spending a certain amount of time in the equipment maintenance shops assisting mechanics and electricians in troubleshooting problems and performing repairs, with particular emphasis on braking and steering systems."

Members of the TEG reemphasized the need for equipment operator training as probably the best approach to reducing mobile equipment accidents.

4. Review of Recommendations to the Bureau of Mines. Members of the TEG submitted many ideas for possible Bureau of Mines sponsorship. The following

list represents the types of projects suggested:

- Training of operators and maintenance personnel.
- Driver alertness investigations.
- More complete and detailed accident data.
- Component/system failure analyses.
- Component development and demonstration:
 - Warning devices (audio and visual) to reliably indicate that emergency steering system is in operation.
 - Warning devices to reliably indicate degradation of power source.
 - Accumulator and accumulator charging systems.
 - Unloading valves.
 - Reliable flow sensing/measuring devices.
 - Definition of seal technology.
- System studies:
 - Machine dynamics.
 - Machine design criteria.
 - System and component reliability investigations.
- Development and demonstration of retrofit emergency steering systems.
- Develop cold temperature version of SAE J53.



- Gather statistical data on status of emergency steering systems in the use in the field.
- Status report of the use of fire resistant hydraulic fluids.
- Investigation of the application of diagnostics to mobile mining machines.

Much of the TEG discussion revolved around the definition of the Bureau of Mines' role in equipment research versus the role of private industry. Many of the suggested projects are presently underway in the engineering offices of component suppliers and equipment manufacturers. It was generally agreed (but not unanimously) that the current efforts underway by private industry are satisfactory in areas of component and system development.

There is, however, evidence that private industry has not solved steering problems completely. Mr. Gary Hayes wrote:

"In the Berkeley Pit truck operation we have only four 150 ton trucks utilizing steering systems that require accumulator/unloading valves. This steering system, without a doubt, is the largest single reason that the trucks are non-productive. Oil contamination, and the complexity of the unloading system, are the main reasons this system is not reliable. It is too sensitive to heat and contamination."

Mr. Hayes also commented on the desirability of warning systems that would reliably indicate degradation of power sources. These would be very helpful in reducing maintenance costs, if they are in fact reliable.



The development of operator and maintenance personnel training programs was judged to be a proper area for Bureau of Mines support. The evaluation of the effects of fire resistant fluids on hydraulic systems would be of importance to the mining industry and to the component and equipment manufacturers. The education or training of MSHA field personnel on the basic elements of steering systems and their maintenance would be of value. Mine personnel would like information on the maintenance and replacement of seals in hydraulic systems. A booklet describing the important maintenance practices for hydraulic systems would be useful. The input from these discussions has been used to help formulate the recommendations given in Executive Summary and Section 8.0 of this report.

SECTION 6.0

EMERGENCY STEERING PERFORMANCE STANDARDS

Industry and government groups have been working toward the development of a standard that would define the emergency steering performance required from off-highway machines. These activities have been underway for several years; two major efforts were culminated during 1978.

Until 1978, regulatory agencies that were interested in promulgating requirements for emergency steering capability had no technical standards to reference. The emergency steering regulations effective in Alberta and British Columbia are examples that illustrate the desire for providing emergency steering capability. These regulations (reproduced in Section 5.1, page 149) provide a "qualitative" approach to requiring emergency steering; the attainment of the required capability is somewhat subjective. A technical standard that provides a quantitative minimum performance requirement would assure a known emergency steering capability. The preparation of such a performance standard was recently completed by the Society of Automotive Engineers, Inc. (SAE). Subcommittee 19, "Steering and Controls," of the SAE Off-Road Machinery Technical Committee established an ad hoc committee to address the need for an emergency steering performance standard. This ad hoc committee, composed of representatives from the equipment manufacturers and steering component manufacturers, held dozens of meetings, conducted field test programs, and prepared draft performance standards for review and comment. This effort resulted in the development and SAE approval of SAE Recommended Practice J53, "Minimum Performance Criteria for Emergency Steering of Wheeled Earthmoving Construction Machines." This SAE Recommended



Practice is reproduced in Appendix A of this report. This standard can be summarized as follows:

1. Applies to scrapers, wheeled front-end loaders, wheeled tractors, motor graders, and off-road haulage trucks that have a maximum speed capability of 20 km/h or greater.
2. Provides steering performance requirements in the event of steering power source failure. This standard does not define steering performance in the event of steering component failures (burst hydraulic hose, broken wheel spindle, hydraulic pump failure, etc.).
3. Defines the steering test course and test procedure to demonstrate satisfactory emergency steering performance.
4. Contains requirements for alerting the machine operator that the primary steering is inoperable and that the machine is on emergency steering operation.
5. Specifies the maximum human effort required to turn steering wheel during emergency maneuvers through the steering test course.

During the period of time when SAE was preparing SAE Recommended Practice J53, the International Organization for Standardization (ISO) was also active in discussing the need for an emergency steering standard. The development of SAE J53 has served to precipitate a position with many ISO members that SAE J53 be considered as the basis for an ISO standard. This position resulted in the conduct of a "technical negotiation" between ISO and SAE on several aspects of SAE J53.



In October 1978, the annual meeting of Technical Committee 127, "Earthmoving Machinery," of the ISO was held near Phoenix, Arizona. Among the many technical areas covered in this week-long meeting was the subject of steering performance requirements. Meeting attendees represented Germany, Italy, Japan, Poland, Russia, the United Kingdom, and the United States. The primary discussion topics relative to steering performance standards were:

1. The emergency steering standard should not be required of low top speed machines that can depend on using brakes to stop in the event of a steering power source failure. At what top speed capability should the emergency steering performance requirement be applicable? Poland and the USSR presented opinions that the emergency steering standard should apply only to equipment with maximum speeds greater than 30 km/h (18.75 mph). Poland was willing to accept Germany's recommendation that 25 km/h (15.6 mph) be specified. Italy, Japan, and the USA agreed that equipment with maximum speeds greater than 20 km/h (12.5 mph) should have emergency steering capability. The USA argued that many types and models of equipment that had maximum speeds less than 25 km/h needed emergency steering to prevent serious accidents. After much discussion, a vote was taken on specifying that the emergency steering requirements applied to equipment with maximum speed capability over 20 km/h. The proposal was approved by vote of five yes – three no.

2. Should a steering standard covering off-highway earthmoving equipment be included with an on-highway earthmoving equipment standard?
The Technical Committee voted to maintain a separation of these two areas.

The action taken by ISO TC 127 at the 1978 meeting is consistent with the contents of SAE J53. It appears that a future steering standard approved and published by ISO would not be in disagreement with SAE J53.



SECTION 7.0

CONCLUSIONS

Preparation of this section of this report was performed by weighing carefully the technical efforts of the Woodward Associates, Inc. project personnel; the many discussions held with members of the Technical Evaluation Group, informally between meetings and during the conduct of the TEG meetings; the steering-related accident data gathered from U.S. and British Columbia sources; and by considering the other Bureau of Mines activities in the area of mobile mining equipment safety. The conclusions presented in this section, and the recommendations presented in Section 8.0, attempt to place the safety aspects of mobile mining equipment steering systems in perspective with other important areas of mobile mining equipment safety.

Research conducted on this project, coupled with information gathered on other Bureau of Mines mobile mining equipment safety projects, prompts Woodward Associates, Inc. to suggest that the following rank-ordered list of safety research areas reflect the cause/source of accidents involving surface mining equipment:

1. Proper Machine Operator Training

It is disturbing to read accident reports describing the serious injury or death of an inexperienced untrained equipment operator. These reports are not uncommon. Though each equipment operator, regardless of age, experience, or previous qualifications, should be given adequate training on the specific type



and model of machine he is expected to operate, it is especially true that a young, newly hired miner with no equipment operating experience is particularly vulnerable to being involved in an accident.

The training regulations recently promulgated by MSHA should have a significant effect in reducing accidents experienced by new equipment operators. It is, of course, important that the operator training programs be oriented toward teaching the equipment operator the material he needs to know to assure that he has the opportunity to avoid situations leading to accidents and that he has received accelerated experience in escaping from abnormal operating conditions that could lead to an accident.

Operator training programs have the potential of having the largest impact in reducing mobile equipment accidents.

2. Operator Protection Systems

The combination of a rollover protective structure (ROPS), a falling object protective structure (FOPS), and a seat belt produces an increase in equipment operator safety that is higher than that attained by any other safety accessory. Of the 1021 injury and fatal accidents reviewed from MSHA-HSAC files, 271, or 26.5 percent, might have been less severe or resulted in no injury if an operator protection system were installed and in use. Rollovers, collisions, falling materials, and other accidents



that require operator protection structures are generally more severe than some other categories of accidents. In the 1021 MSHA-HSAC accidents reviewed, 109, or 10.7 percent, resulted in fatalities. Of the 271 accidents where an operator protection system might have helped, 66, or 24 percent, resulted in deaths. It is recognized that proper operator training, as advocated in section above, will reduce the number of rollover and collision accidents. Training will have some effect on reducing falling material accidents, however, many falling material accidents are not within the equipment operator's influence.

3. Ingress/Egress of Machines

Slips/falls, while not resulting in many fatal injuries, produce a large number of accidents resulting in lost-time injuries. Of the 1021 MSHA-HSAC accidents reviewed, 226, or 22 percent, were slips/falls related to the ladder systems on equipment. Again, proper training will help reduce these accidents. Improved ingress/egress systems will also have a significant impact on slip/fall accidents.

4. Equipment Maintenance Activities

Though not quantified during this study, Woodward Associates, Inc. researchers have noted significant numbers of injury and fatal accidents occurring during the performance of equipment maintenance. Operator training will not have an effect on these accidents directly. In an indirect manner, proper operation and



reduced damage frequency will result in less maintenance activities resulting in lower exposure for maintenance personnel.

The four items listed above are applicable to all types of surface mining machines. Other important areas of safety research that are of lesser general importance to overall surface mine equipment safety but may have specific importance to particular generic types or certain equipment work practices are listed below:

- Equipment fires
- Work place illumination
- Obstructed visibility
- Braking systems

The potential reduction in steering-related accidents that might be realized through the development of steering systems with higher reliability is small relative to the accident reduction possibilities represented by the items discussed earlier in this section. There are improvements in steering system technology that will result in reduced downtime because of higher reliability and lower maintenance requirements. These improvements would not have a significant direct effect on reducing steering-related accidents. Woodward Associates, Inc. has concluded that the use of Bureau of Mines safety research funds to aid the development of steering systems with increased reliability is not warranted. Today's state-of-the-technology is producing reliable steering systems.

It is possible that some actions contemplated by regulatory agencies and by industry could result in a lowering of the reliability of steering systems. The increasing emphasis on the use of fire-resistant fluids in hydraulic systems could have the potential for reducing the steering system reliability. Similarly, a requirement for retrofitting emergency steering

systems on mining equipment could, if not engineered and installed correctly, result in lowering the reliability of the primary steering system.

The capability of continuing the steering function for some period after failure of the engine or steering power source is desirable. Emergency (sometimes called supplementary or auxiliary) steering capability is desirable in machines that have maximum speed capabilities beyond the speed where the braking system can stop the machine in a short distance. It is preferred that the emergency steering system actuate automatically without need for an operator action. Some existing emergency steering systems require that the operator flip a switch. It is also important that the operator be alerted by visual and/or audio means that the emergency steering system is operating.

Section 8.0 presents the recommendations developed from these conclusions and from review of other Bureau of Mines research activities.

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SECTION 8.0
RECOMMENDATIONS

The Bureau of Mines is sponsoring a broad range of equipment safety research. The following recommendations are influenced by a larger view than that of the steering system needs alone. It is Woodward Associates' recommendation that the Bureau initiate no additional safety research, studies, or demonstrations solely oriented toward mobile mining equipment steering systems. The efforts of the equipment manufacturers and the steering system component suppliers are completely satisfactory to assure continued technology advancement. There are areas of endeavor that could be enhanced by Bureau of Mines involvement. These areas are covered by the following recommendations:

1. Continue the development and demonstration of materials and techniques that can be used in the training of equipment operators. The training of equipment operators to handle emergency or abnormal events experienced during equipment operation is especially important. (The Bureau has projects underway in this area.)
2. Include steering system inspection procedures as an integral part of equipment operator training programs. (The Bureau is following this recommendation on some projects.)
3. Assist the Mine Safety and Health Administration personnel in becoming technically conversant on desirable steering system features such as

emergency steering capability, and on the general approaches to proper steering system maintenance.

4. Conduct an evaluation of the potential positive and negative effects of requirements to use fire resistant fluids in the hydraulic systems of mobile mining equipment.

While this recommendation is prompted through concern for the possible deleterious effects on the steering system, all hydraulic systems on the machines should be studied. Some data may be available from the Canadian provinces and European countries that require the use of fire resistant fluids in hydraulic systems. The relative effects of the different fluids available can be compared and the overall benefit/detriment determined.

The above recommendations are generally oriented toward addressing the safety of the equipment operator. The following recommendations are generally oriented toward improving the productivity of mining operations and, therefore, may be considered by the Department of Energy as well as the Bureau of Mines:

5. Prepare a booklet presenting guidelines for the maintenance of hydraulic systems on mobile mining equipment. While many large mines have developed excellent maintenance procedures for hydraulic systems, there is a need for guidance and training of new maintenance personnel and for aiding the implementation of structured maintenance programs at mines not presently performing adequate maintenance.



6. Prepare a report describing the function, care, and maintenance of hydraulic system seals on mobile mining equipment. This document should cover installation procedures. Mine maintenance personnel state that seals in hydraulic systems need frequent maintenance attention and that seal damage during replacement is not uncommon.

In addition to examining possible areas where the Bureau of Mines might take action, Woodward Associates, Inc. observed that there were areas where the Mine Safety and Health Administration could contribute to the validity of Bureau of Mine safety research projects and could, through performance of technical aid and assistance to the mines, enhance the MSHA image.

The following recommendations are directed to the Mine Safety and Health Administration:

1. Improve the quality and quantity of information gathered by the accident investigation team. This need exists for both the fatal accident reports and the injury accident reports. This improvement can be achieved through several approaches:
 - Involve technical experts from the equipment manufacturers in certain accidents involving their equipment models. WAI has received assurances from 19 equipment manufacturing companies that they would participate in accident investigations.
 - Prepare accident investigations and data recording guidelines for use by



the mining industry. These guidelines might seem simple and obvious to experienced accident investigators, but would be extremely valuable to the designated safety person at a small mine operation. Educating mine safety personnel on the value of accident analyses would help promote more thorough investigations.

- Include accident-related information that may not be obviously related to the injured person but is important to the understanding of the accident causative factors. The outcome of the accident is also important. Was the damage to the equipment minor or major? Were other employees endangered by the equipment operator's actions? The whole accident scenario is useful and does not require much additional effort by the mine's safety person.
- An educational/training program for some HSAC personnel might help them in their interpretation of information presented on accident reports. Familiarization with mining terminology and equipment descriptions would aid their efforts to correctly categorize some accidents.
- Direct follow-up by the HSAC personnel with the mine reporting an accident would be beneficial in instances where the accident report is illegible, incomplete, or difficult to interpret. A short telephone call to the mine person filling out the accident report might clarify many questions about an



accident. This information audit would significantly increase the quality and quantity of information on the accident reports.

- A "serious incident" reporting system would help define potential injury and death producing accident situations. British Columbia mines report incidents not resulting in injury or death to personnel to the Department of Mines and Petroleum Resources. Narrative summaries of these incidents are broadly distributed to British Columbia mines to alert them to potential accident situations. While feedback to the mines might be more difficult in the United States, the value of the incoming information would be high to HSAC and Bureau of Mines safety projects. The mine's safety person could call a toll-free telephone number and relate the incident to an HSAC employee trained to gather the important information. This call could be recorded for later transfer to a standard form and coded for computer storage and retrieval.

2. Provide technical information for distribution by MSHA field personnel to the mines. Specifically, in the area of equipment steering systems, provide information on inspection procedures, on emergency steering performance standards (SAE Recommended Practice J53), and on industry accident experience.



A goal of this activity would be to have the mines perceive MSHA as a partner in safety and not as an adversary.

3. In reviewing training plans and training programs being prepared and implemented by the mining industry, offer suggestions on the need for training the equipment operators to correctly anticipate and handle emergency or abnormal operational situations. While some accidents do occur during the normal operation of a machine, many accidents are the result of the equipment operator not having the knowledge or training necessary to react quickly to a developing emergency. If the engine fails, if a tire blows out, or if the brakes or steering malfunction, will the operator be able to avoid an accident?

The above recommendations for Bureau of Mines and MSHA consideration affect a much broader sign of activity than mobile surface mining equipment steering systems. As stated earlier in this report the steering systems being produced by the mining equipment industry are reliable and do not present a safety problem. The equipment manufacturing industry is active in the development of new steering systems that will retain the demonstrated safe characteristics. Voluntary consensus standards have been developed to help assure minimum performance levels of emergency steering systems. Similar standards are being developed for the primary steering systems.



APPENDIX A
SAE RECOMMENDED PRACTICE J53



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Minimum Performance Criteria for Emergency Steering of Wheeled Earthmoving Construction Machines — SAE J53

SAE Recommended Practice
Approved December 1978

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HANDBOOK.

Society of Automotive Engineers, Inc.
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MINIMUM PERFORMANCE CRITERIA FOR EMERGENCY STEERING OF WHEELED EARTHMOVING CONSTRUCTION MACHINES—SAE J53

SAE Recommended Practice

Report of Off-Road Machinery Technical Committee approved December 1978. Rationale statement available.

1. Objective—This SAE Recommended Practice provides minimum performance and test criteria for the emergency steering of specified machines in the event of an engine or steering power source failure. This criteria shall enable machine manufacturers to uniformly evaluate emergency steering capability.

2. Scope—This recommended practice is specifically limited to tractor scrapers, wheel loaders, wheel tractors, graders, and dumpers (as defined in SAE J1116 (January, 1977) and J1057a (June, 1975)) which are designed to operate at a maximum rated speed in excess of 20.0 km/h (12.4 mph) and which employ power source(s) in addition to the operator control effort to effect machine steering.

3. Definitions

3.1 Steering System—The means by which the machine is controlled about the vertical axis.

3.2 Steering Power Source—The means for generating power to produce steering (e.g., pump, generator, etc.).

3.3 Steering Control Effort—The force exerted by the operator when steering the machine. For the steering wheel, this force is considered to be exerted at the rim.

3.4 Maximum Axle Spacing (MAS)—The centerline distance from the forward-most axle to the rear-most axle.

3.5 Tire Track Circle (TTC)—The outside diameter of the tire track when the machine is steered to its limit and run in a continuous path.

3.6 Failure—Sudden and complete loss of the engine or steering power source output.

4. Performance Criteria

4.1 In the event of failure of an engine or a steering power source, a means shall be provided to continue maintaining steering control of the machine. As a minimum, the machine must be capable of negotiating the appropriate test course shown in Fig. 1.

4.2 The normal means provided the operator for steering control, (e.g., wheel, switch, lever, pedal, etc.) of the machine will continue to be used in the event of an engine or a steering power source failure. Emergency steering capability after failure shall be provided without requiring a supplementary operator control function (e.g., turning a switch, pulling a knob, etc.).

4.3 Required steering wheel effort while negotiating the test courses must be within the acceptable range as specified by Fig. 3. All other means of control (switch, lever, pedal, etc.) must not exceed the force levels shown in the Controls Section of Military Equipment and Facilities, MIL-STD-1472.

4.4 A warning device indicating an engine or steering power source failure is required for machines which will not negotiate the Fig. 1 test course when using only operator muscular power within the limits of paragraph 4.3 and with no power assist devices. This warning device shall be audible and/or visual and shall actuate after failure. After actuation, the steering capability shall be at least the minimum amount required for one trip through the Fig. 1 test course.

A warning device is not required for machines which will negotiate the Fig. 1 test course when using only operator muscular power within the limits of paragraph 4.3 and with no power assist devices.

4.5 Emergency steering response, including any time delay introduced by an engine or a steering power source failure, must permit the machine to stay within the boundaries of the Fig. 2 test course.

4.6 Machines that have maximum rated speeds in excess of 20.0 km/h (12.4 mph) in reverse must have similar emergency steering capability (force, rate, and duration), in either forward or reverse direction and should be tested in the forward direction. Tests can be conducted in the reverse direction in addition to the forward direction if normal machine use dictates.

4.7 Machines having different steering performance in right and left hand turns must comply with the appropriate Test Courses shown on Figs. 1 and 2 and with a mirror image of Figs. 1 and 2.

5. Test Course

5.1 The test courses are to be constructed in accordance with Figs. 1 and 2 on a compacted or paved surface. A mirror image of either course may be used, provided the steering performance in right and left hand turns is equal.

5.2 The test courses shall not exceed 1 1/2% grade in any direction.

6. Test Procedures

6.1 Test Machine Specifications

6.1.1 All component parameters related to emergency steering capability shall be within the manufacturer's specifications. Machines with optional tire sizes should be tested with the arrangement which requires the greatest amount of steering. This is normally represented by the smallest tire track circle.

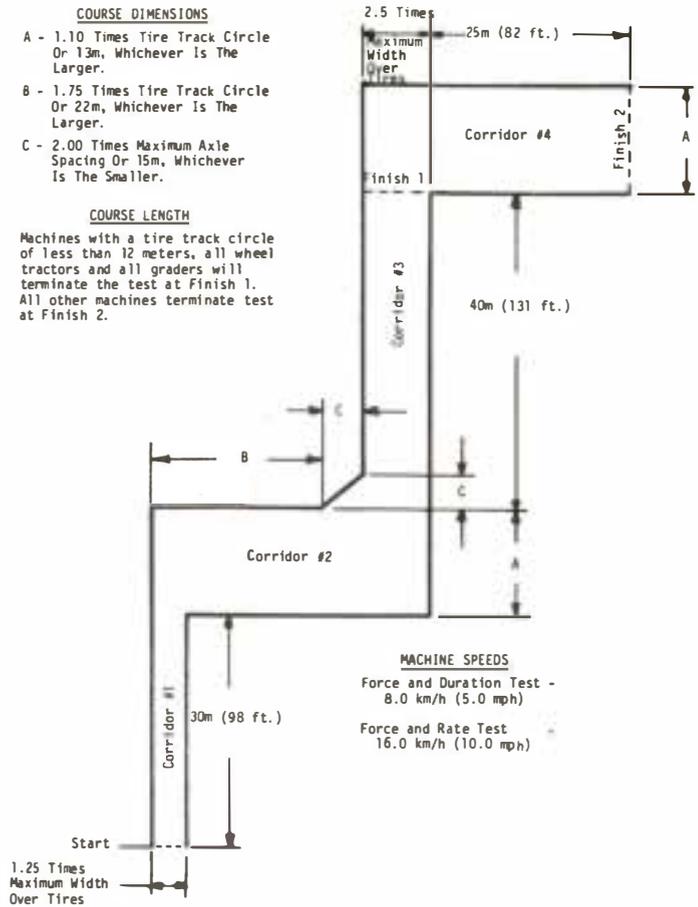


FIG. 1—EMERGENCY STEERING FORCE, RATE, AND DURATION TEST COURSE

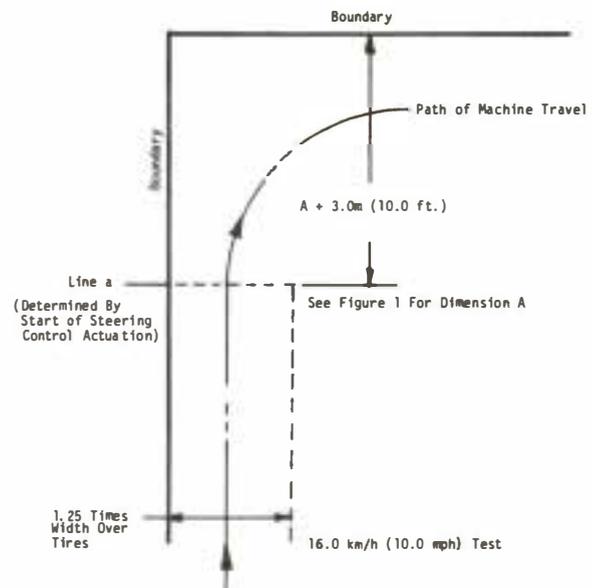


FIG. 2—EMERGENCY STEERING RESPONSE TEST COURSE

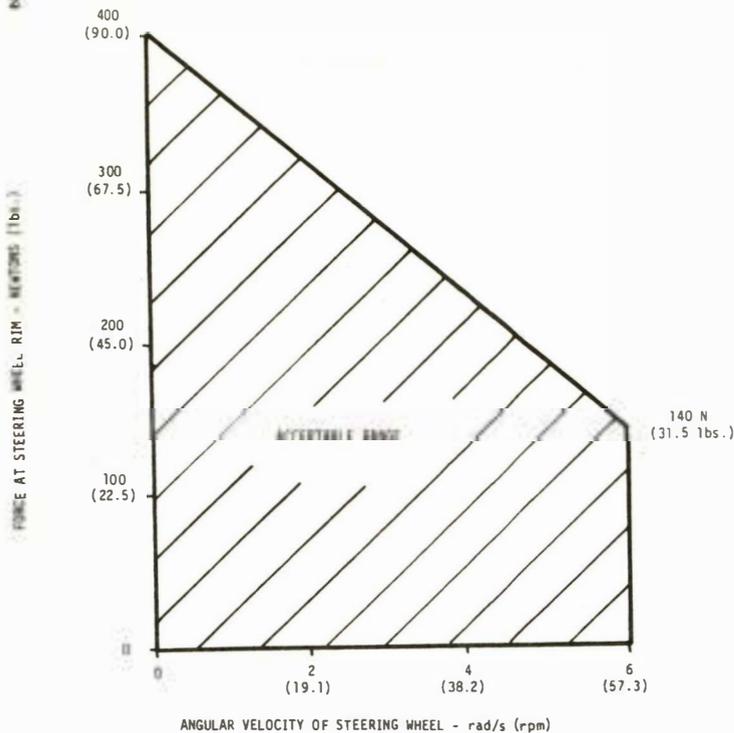


FIG. 3—STEERING WHEEL EFFORT

6.1.2 Tractor scrapers and dumpers are to be loaded to the manufacturer's gross machine weight ratings and distribution, including the weight of the heaviest combination of attachments approved by the manufacturer.

6.1.3 Wheel loaders, wheel tractors, and graders are to be at manufacturer's empty machine weight ratings and distribution, including the weight of the heaviest combination of attachments approved by the manufacturer.

6.2 The tire track circle (used in calculating the test course dimensions) is to be determined as follows:

6.2.1 Use only the steering capability provided by the primary steering control means (e.g., steering wheel).

6.2.2 The tire track circle is to be determined on the same ground surface conditions (grade, rolling resistance, tractive coefficient, etc.) on which the test courses are to be constructed.

6.2.3 The machine is to be steered to its limit and driven in a continuous circular path between 2.0 and 4.0 km/h inclusive in order to describe the tire track paths on the ground surface. The tire track circle is the maximum diameter of the described paths. Suitable marking devices may be used in lieu of the actual tire print to establish the tire track path.

For the following machines as classified in SAE J1057a (June, 1975) and similar configurations;

4.1.1.4, 4.2.1.1, 4.3.1.2, 4.3.1.3, 4.3.1.4,
5.1.3, 5.1.4, 5.1.5, 5.2.3, and 5.2.4

the tire track circle should be determined for only the leading unit (prime mover) which excludes possible steering top interference between the prime mover and the trailing units.

6.2.4 For machines with different right and left hand steering capabilities, use the smaller tire track circle in calculating the test course dimensions.

6.3 The machine is to be driven through the Fig. 1 test course with a steering power source inactive (to simulate a power source failure). Other machine functions, which might be automatically triggered by the simulated steering power source failure and thus affect driving thru the test course, may be rendered inoperative providing such action does not increase the emergency steering capability above the level normally available.

6.3.1 At 8.0 km/h (5.0 mph) \pm 15% to verify the emergency steering force and duration. Tire tracks must stay within the test course boundaries except for the tire tracks of the trailing unit(s) for the following machines as classified in SAE J1057a (June, 1975) and similar configurations;

4.1.1.4, 4.2.1.1, 4.3.1.2, 4.3.1.3, 4.3.1.4,
5.1.3, 5.1.4, 5.1.5, 5.2.3, and 5.2.4.

6.3.2 At 16.0 km/h (10.0 mph) \pm 15% to verify the emergency steering force and rate. Tire tracks must stay within the test course boundaries except for the tire tracks of the trailing unit(s) for the following machines as classified in SAE J1057a (June, 1975) and similar configurations;

4.1.1.4, 4.2.1.1, 4.3.1.2, 4.3.1.3, 4.3.1.4,
5.1.3, 5.1.4, 5.1.5, 5.2.3, and 5.2.4.

6.4 Verify that the steering wheel or steering control effort required to steer through the Fig. 1 test course does not exceed levels described in paragraph 4.3.

6.5 Verify the warning function as described in paragraph 4.4.

6.6 Verify the emergency steering response as described in paragraph 4.5 by driving the machine through the test course shown in Fig. 2 at 16.0 km/h (10.0 mph) \pm 15%. Enter the test course with full steering system capability. Initiate a turn at Line a. Start of steering control actuation should trigger a ground marker located under the front axle, and simultaneously simulate a steering power source failure. The machine must complete a 90 deg turn with the tire track paths remaining within the boundaries specified.

This verification is not required for steering systems which experience no time delay introduced by an engine or steering power source failure.

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