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Measurement of Suspension and Ride Characteristics of the M1 Main Battle Tank

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Personnel operating the M1 tank are subjected to an extremely harsh vibrational environment as the vehicle traverses rough terrain and performs the severe maneuvers which are a routine part of its operational function. When this environment exists at a high level for an extended period of time, the effectiveness of the tank personnel can be severely diminished, even to the point of inability to function at all. Means have been developed to measure the effect of this vibration on human subjects so as to determine the limits to which they may be taken in terms of operating effectiveness and also in terms of physical well being. This paper describes (1) improved hardware for making these measurements, (2) a method for relating tank hull input forces to ride quality, and (3) installation and calibration of instrumentation to measure the hull forces.

INTRODUCTION

The US Army's M1 Main Battle Tank (Figure 1) is a very heavy vehicle which is required to operate in a wide variety of difficult cross-country terrains. At a weight of 65 tons, the tank's top speed of 41 mph can give rise to vibrational environments containing large amplitude components over a wide frequency range from 1 Hz or less to the high frequencies associated with shock forces of the suspension system "bottoming out." These vibrations are imposed on both the tank hull and its occupants. The hull design allows the tank to withstand a higher level of vibration than can be tolerated by the crew members, so human response limits the severity of the conditions under which the vehicle can operate. Because of this limit, it is necessary first of all to establish the ranges of vibrational environments over which the human operator can function effectively, and secondly, to devise some means of characterizing this environment in a readily measurable way. Both of these requirements have been met to a degree by a large amount of experimental research and development over the past two decades, but there still remains some lack of agreement as to the level of vibration in a given frequency range that the human body can safely tolerate and continue to function effectively, and there is always room for improvement in devices designed to give a measure of ride quality based on vibrational amplitudes and frequencies.

In addition to experimental research aimed at established human limits, it is also desirable to relate this ride quality to the input forces transmitted to the tank hull through the suspension system. By correlating these forces with the ride quality, the various computer models of the tank (which are used in design and analysis studies) can be made to output a ride quality indication from any and all scenarios of tank operation. This will provide a relatively inexpensive means of, for example, a parametric study of tank suspension as it relates to operator effectiveness. The correlation of input forces with ride quality must come from field testing in which both quantities are measured simultaneously. To this end, the Instrumentation Services Division (ISD) of the Waterways Experiment Station (WES) has designed and constructed an improved ride meter which quantifies ride quality and has instrumented and calibrated the suspension system of an M1 tank in order to measure hull input forces. The remainder of this paper will describe these two activities in detail.

Figure 1. M1 Tank

It is noted that ISD performed this work for the Mobility Systems Division (MSD) under the sponsorship of the US Army Corps of Engineers and the US Army Tank-Automotive Command (TACOM).

RIDE QUALITY MEASUREMENT

In the effort to provide a manageable quantity which indicates ride quality, two basic methods have emerged over the years as being most indicative of ride quality. Both of these methods weigh amplitude of vibration as a function of frequency so that those frequencies which are most harmful to the human body (through visceral resonances, for example) are assigned a higher weight and thereby contribute more substantially to the output of the method, which in both cases is a single number which reflects the severity of the ride. Since both methods employ a weighted frequency spectrum, they give comparable assessments of ride quality, but there is still some discussion as to which is the better indicator.

The weighting functions for these methods are shown in Figure 2. Note that the quantity being weighted is a signal from an accelerometer located at some point on the tank hull usually on the seat of an occupant. The figure shows two smooth curves and a set of discrete points. The discrete points represent center frequencies of the 1/3-octave filters. The rms acceleration of the output of each filter is determined and used as a measure of ride quality. This is the International Standards Organization (ISO) standard for describing human response to whole-body vibration. In practice, ISO prefers to have the measured rms level at each 1/3-octave center frequency compared with recommended values, but for complex vibrations it is desirable to have a single number representing the overall weighted rms acceleration. To this end, the Society of Automotive Engineers (SAE) had a ride meter constructed with a smooth filter indicated by the solid curve of Figure 2. Note that this curve essentially passes through the center frequencies of the 1/3-octave filters. The remaining curve, shown by the broken line, is the standard filter for ride meters used by the US Army to evaluate vehicle ride quality. The major differences in these two smooth curves can be seen to be the frequency of maximum weighting and the frequency spread. While the SAE/ISO meter outputs a single number representing a rms acceleration, the WES ride meter, using the Army standard filter, gives an overall value of mean-square acceleration which represents vibrational power. Thus, the output of the WES ride meter is considered to be proportional to the power absorbed by the human body and is therefore referred to as an absorbed power meter. With proper scaling, this output can be specified directly in watts of absorbed power. This provides a simple yet powerful measure of ride quality, since it is readily compared to the presently accepted value of six watts as an upper bound to crew effectiveness.

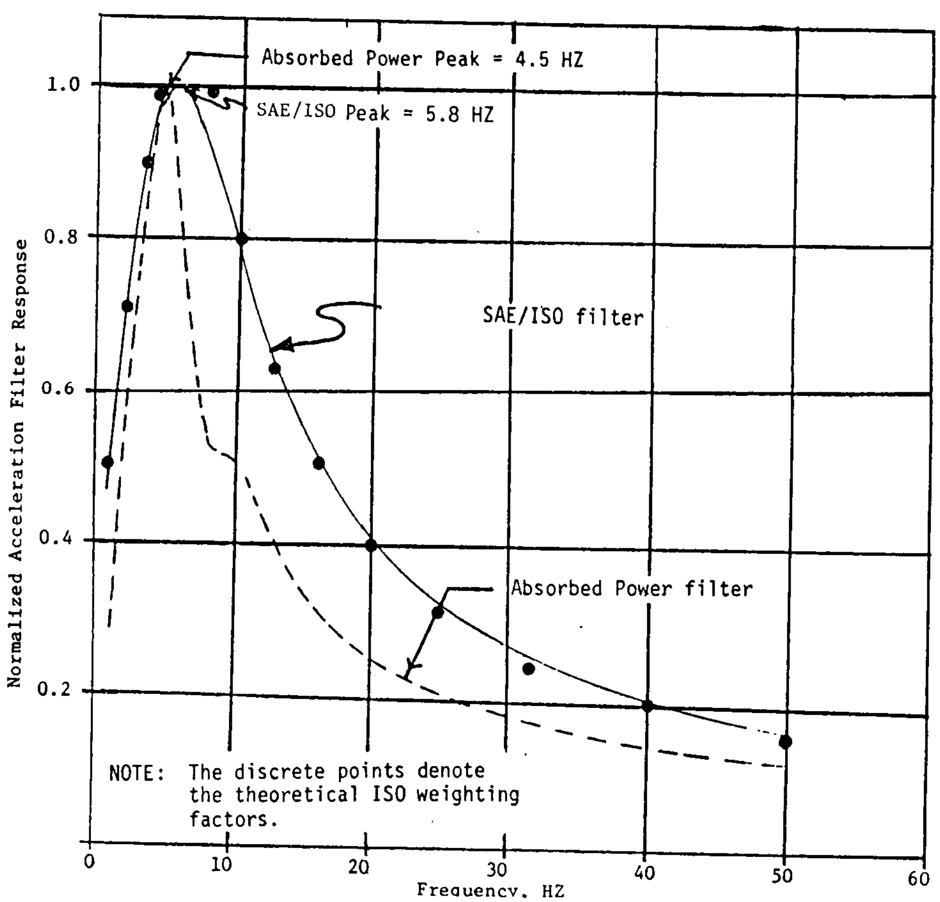

Figure 2 Normalized filter responses

Human Body Vibration Response Curves

The information on the ride meter given above was taken for the most part from a WES technical report by Murphy and Ahmad[1]. This report has several references on human body response which are included here as a bibliography.

DEVELOPMENT OF THE WES RIDE METER

At the request of the Mobility Systems Division, ISD designed and constructed a ride meter whose function was to measure the absorbed power weighted according to the Army standard filter characteristics. This system is shown in Figure 3 and includes the ride meter, the output indicator with clipboard for recording data, and the input accelerometer in its mounting case. As a matter of interest, an identical servo-accelerometer is included in the photograph. Figure 4 is a close-up view of the ride meter with top cover removed showing power and accelerometer inputs through the cables on the left, the function selector switch on the operator panel, and the several PC boards containing ride meter circuitry. The panel also contains an off-on switch and reset button for manually controlling the time interval over which the accelerometer signal is processed. A close-up of the output indicator and clipboard is shown in Figure 5. Here it is seen that any of three display positions can be selected and read out on the digital voltmeter. At the conclusion of a test run, the ride meter contains information on the total time of the run and on the number indicating absorbed power. Both of these pieces of information are in the form of a voltage which is the output of an operational amplifier connected as an integrator. Time is obtained by integrating a constant; absorbed power is obtained by sequentially passing the accelerometer signal through a 30 Hz low pass filter, the Army standard weighting filter, a squaring circuit, and the integrator. These quantities are read out in turn on the digital indicator and recorded on the data sheet. Thereafter, the value of absorbed power in watts is obtained by hand calculation.

Although this initial design ride meter functioned very well, and is currently being used in several applications, it was found desirable to design and construct a new model which had expanded capabilities and performed its functions automatically.

Unlike the original design, which was completely analog in operation, the new design combines analog and digital operations and is consequently referred to as the WES Hybrid Ride Meter. In this design, the system remains analog in nature from the input through the integrator of the weighted acceleration signal, then is converted to digital for further processing and storage in memory.

A block diagram of the hyrid ride meter is shown in Figure 6. The input signal is first passed through a 30 Hz low pass filter because the higher frequencies with corresponding lower amplitudes do not contribute significantly to decreased operator effectiveness. The signal is then scaled appropriately and fed to parallel paths which produce both the absorbed power value and tne ISO rms acceleration value. The output of the integrating amplifiers are monitored and provision is made to avoid saturation of the amplifiers within a microprocessor program.

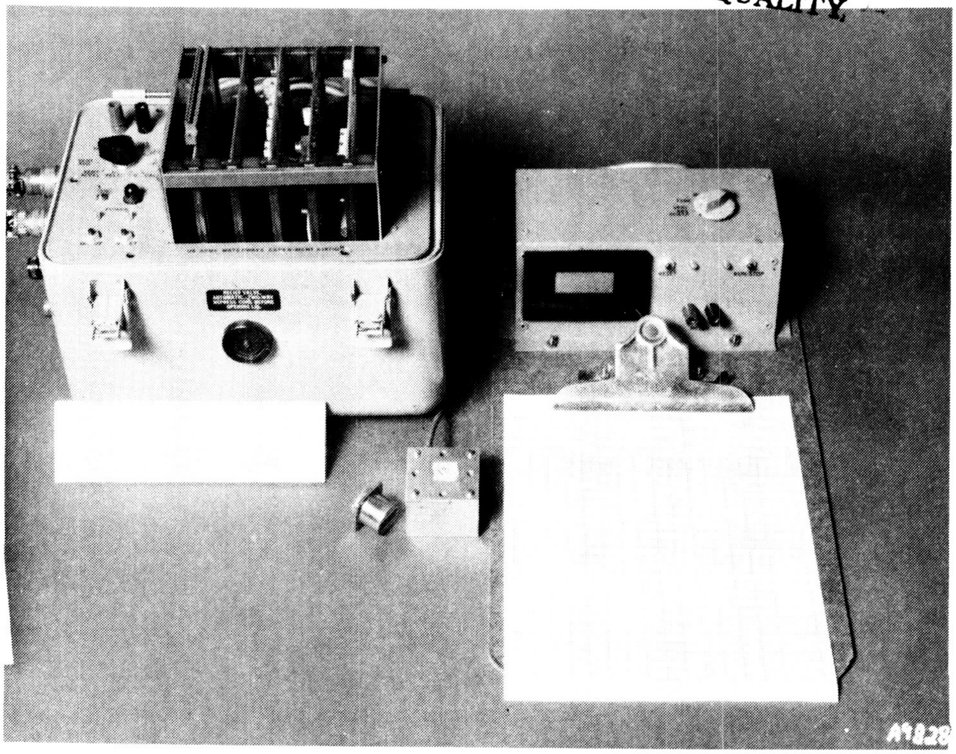

Figure 3. Absorbed Power Ride Meter

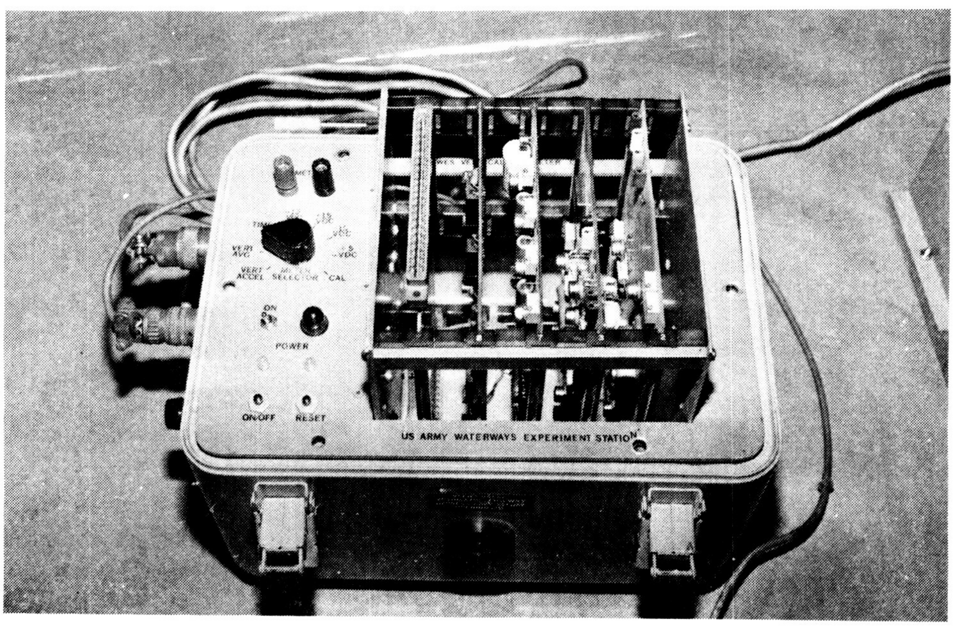

Figure 4. Meter Electronics and Control Module

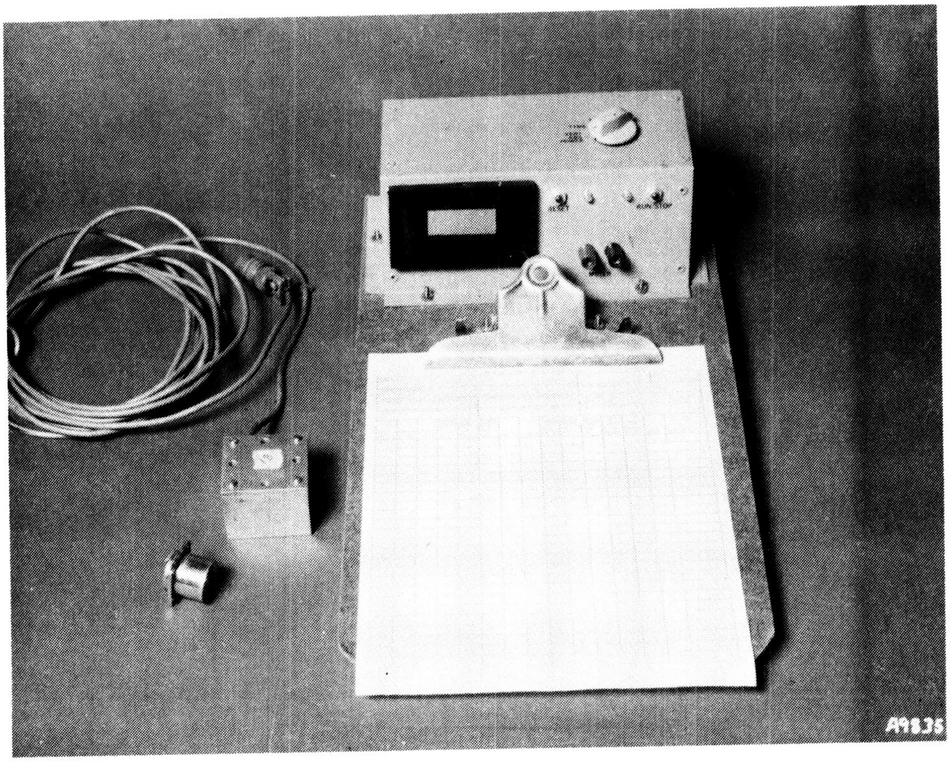

Figure 5. Data Readout and Log Sheet

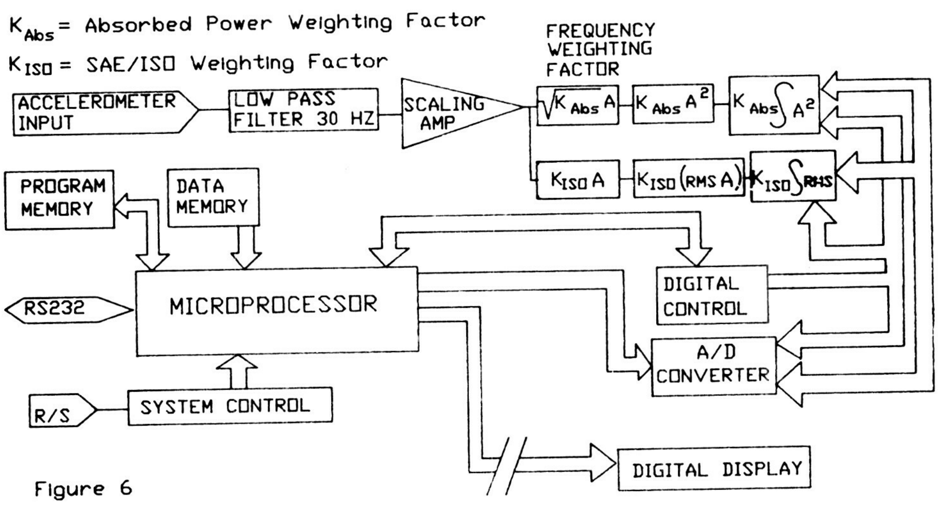

Figure 6

Block Diagram of Micro Based Ride Meter

The hybrid ride meter will allow data to be taken and processed in several different modes so that data acquisition can be tailored to the demands of a particular test program. This is accomplished by controlling the meter operation with a microprocessor and providing memory for the data storage. This memory space is sufficient for 785 tests or continuous recording for up to 12 or 13 hours which provides much greater flexibility than has been heretofore possible. Typically, the accumulated test values are transferred to a computer where they can be formatted and further processed as desired. The WES Hybrid Ride Meter is pictured in Figure 7 with its input accelerometer and a lap-top computer. A close up of the face plate is shown in Figure 8. The ride meter with top removed, Figure 9, shows the internal components. In this view, the right hand slot holds the microprocessor board, shown beside a pen in Figure 10 for size comparison.

This new hybrid ride meter was designed for use in a wide variety of test and measurement situations. Because of the importance of the concept of a single number indicator of ride effect on the human operator and because of the great versatility of the hybrid ride meter, its several functions will be described here in detail.

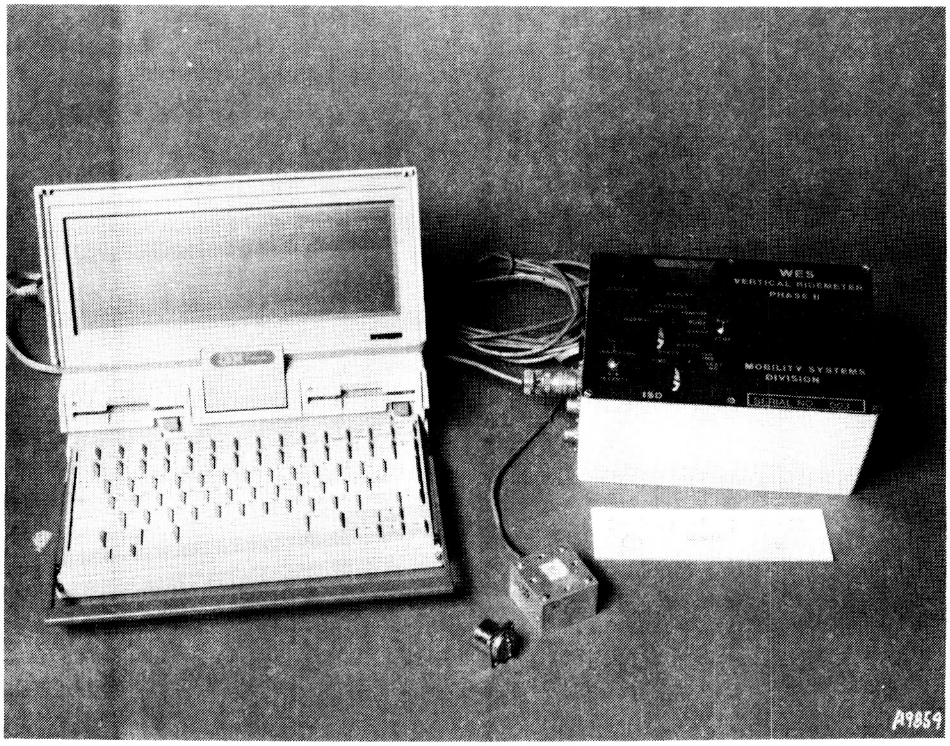

Figure 7. Hybrid Ride Meter System

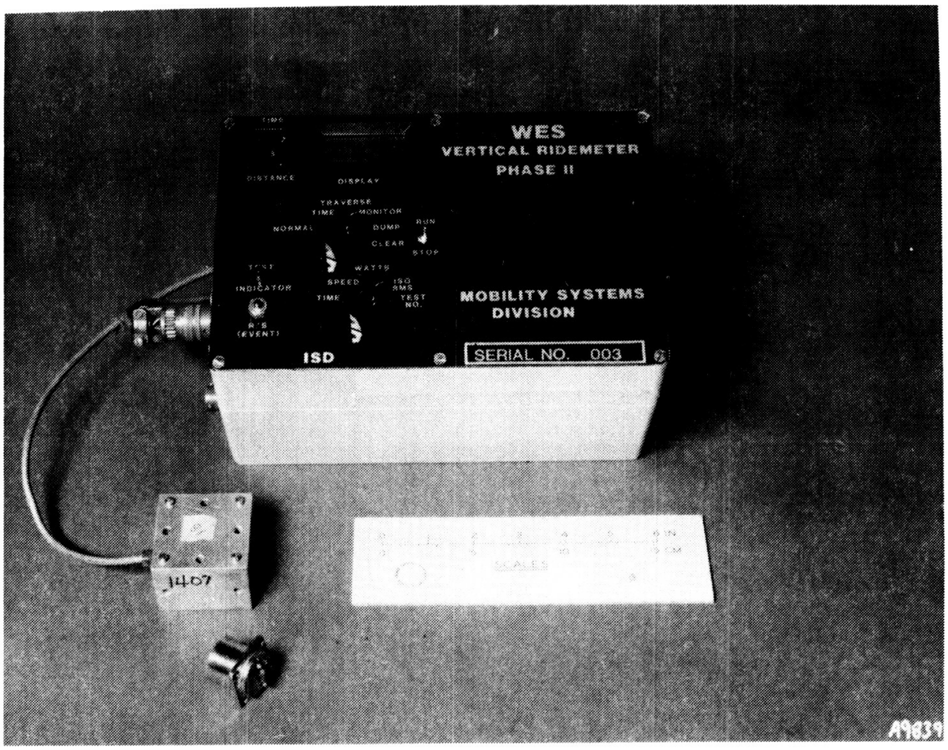

Figure 8. Ride Meter Display and Control Unit with Accelerometer Attached

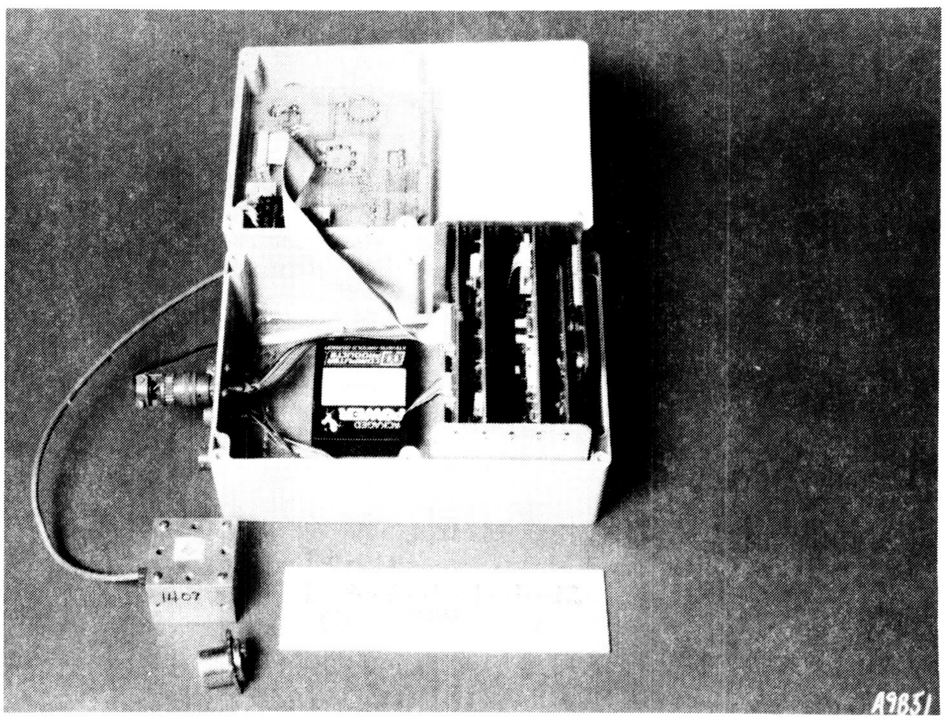

Figure 9. Hybrid Analog and Digital Electronics

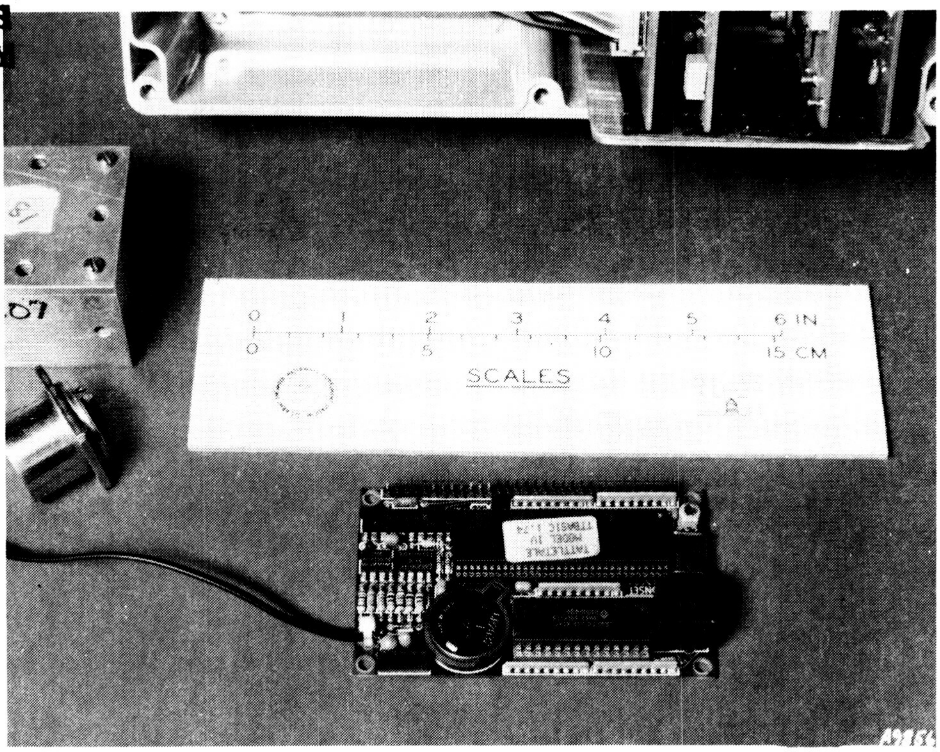

Figure 10. Microprocessor with A/D, Digital IO, and Memory

Figure 11 shows a computer drawing of the face plate with the various switches and controls clearly indicated. The mode selector control and the run-stop switch are located directly below the digital read-out indicator. Below these two controls is a data selector switch which chooses the quantity to be displayed on the indicator when the mode switch is in the MONITOR position. In the lower left corner is the R/S event switch. Pressing this button when the run-stop switch is in the run position causes an interrupt to be sent to the microprocessor commanding it to begin data collection. Pressing R/S again commands the microprocessor to stop data collection. The control in the upper left hand corner is a thumbwheel which selects a number between 0-15 in the display window. With the mode selector set in the NORMAL position, the displayed number represents distance in hundreds of feet. This is the selected course length. Pressing the R/S button begins a test which is terminated by pressing the R/S button when the vehicle has traversed the chosen test length. This course length is compared with time to calculate an average speed through course.

In the TIME position of the mode selector switch, the thumbwheel display number gives a chosen time of test in tens of seconds; that is, a test time of from 10 to 150 seconds can be chosen, in increments of ten seconds. A test is initiated by pressing the R/S button, in which case the test data are based on the actual time of test. In either case, the microprocessor resets the system and starts another test automatically. This operation will continue until the Run/Stop switch is placed in the stop position.

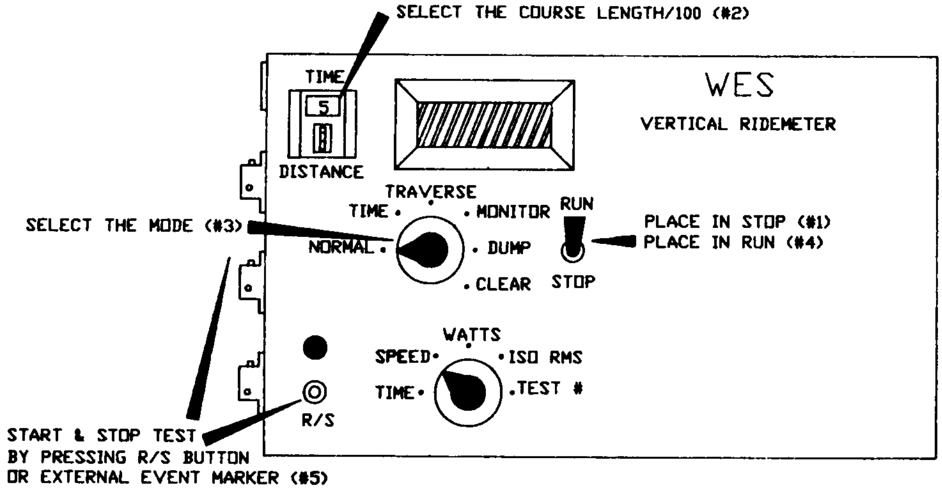

Figure 11.
Hybrid Meter Controls

In addition to the NORMAL and TIME modes, a TRAVERSE data collecting mode is provided. In the traverse mode, the operator will start the system when entering a predetermined course and will activate the event switch at the end of each subcourse segment until the full course has been traversed at which time the stop switch is activated.

The data collected and stored for all three modes are time, absorbed power in watts, and ISO rms acceleration in g's. In addition, speed and distance traveled are collected and stored in the NORMAL mode, and in the other modes if wheel pips are available.

An operator can examine the data at any time by placing the mode selector in the MONITOR position and using the data selector switch. Because the ride meter memory usually contains the results of many individual tests, a means is provided for selecting the desired test number. Placing the data selector in TEST # position produces a display of the most recently completed test numbers. The desired test number is obtained by pressing the R/S button, which causes the displayed test numbers to be incremented or decremented by one, according as the thumbwheel display number is set to 1 (increment) or 0 (decrement). Upon arriving at the chosen test number, the data selector is used to display time, speed, absorbed power, or ISO rms acceleration. When the mode selector is moved off the MONITOR position, the microprocessor will return to the correct test number.

The DUMP postiion of the mode selector switch allows the operator to transfer all test data in the ride meter to a computer file that is LOTUS compatible software. The ride meter is connected to the computer through an RS232 cable, and utilizes a communication software package such as CROSSTALK or MIRROR to effect the transfer. In the DUMP mode, the microprocessor displays a menu to guide the operations. For all modes of operation, the Run/Stop switch is placed in the Stop position before selecting the modes. After setting the mode selector, placing the Run/Stop switch in the run position commands the microprocessor to select the chosen mode.

The final position of the mode selector is CLEAR, which clears all data memory in the ride meter.

The single number ride meter output is desired from an input acceleration signal which is weighted and integrated. To relate this number to operator effectiveness, it is necessary that the acceleration signal reflect as closely as possible the motion experienced by the operator and for this reason, the input signal usually is from an accelerometer fixed to the driver's seat and oriented to sense the vertical component of acceleration. In Figure 12, the position of the accelerometer relative to the driver's body is indicated. This location is deemed to give a reasonable measure of the acceleration felt by the driver. For purposes of comparison, an identical accelerometer is fastened rigidly to the tank floor adjacent to the driver's seat. This can be seen as the small square shape immediately to the right of the seat in Figure 13. A comparison of the ride quality given by these two accelerometers gives a measure of the effectiveness of the seat in protecting the driver from the vibrations felt by the tank hull.

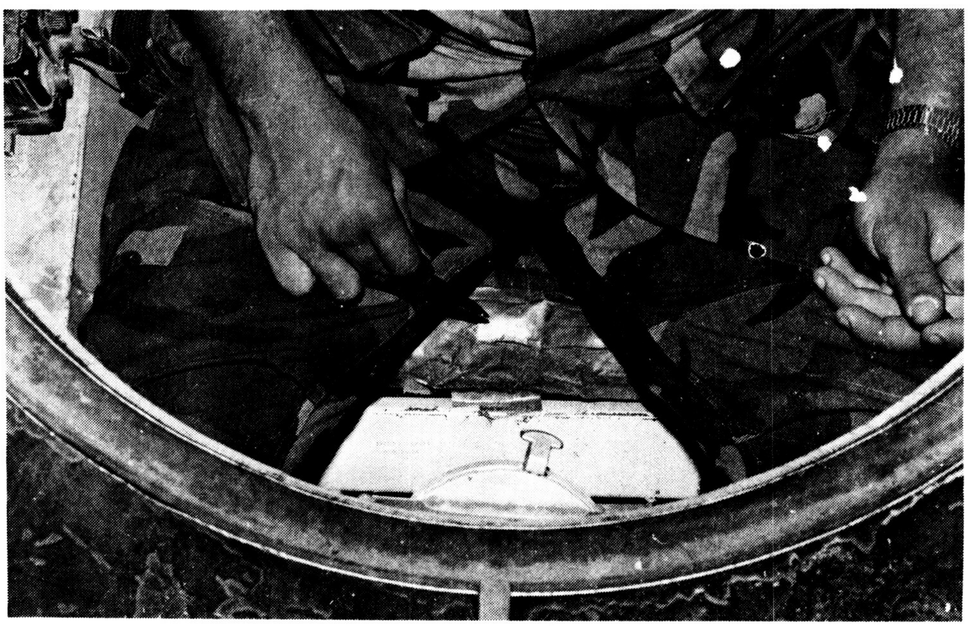

Figure 12. Driver Seat Accelerometer

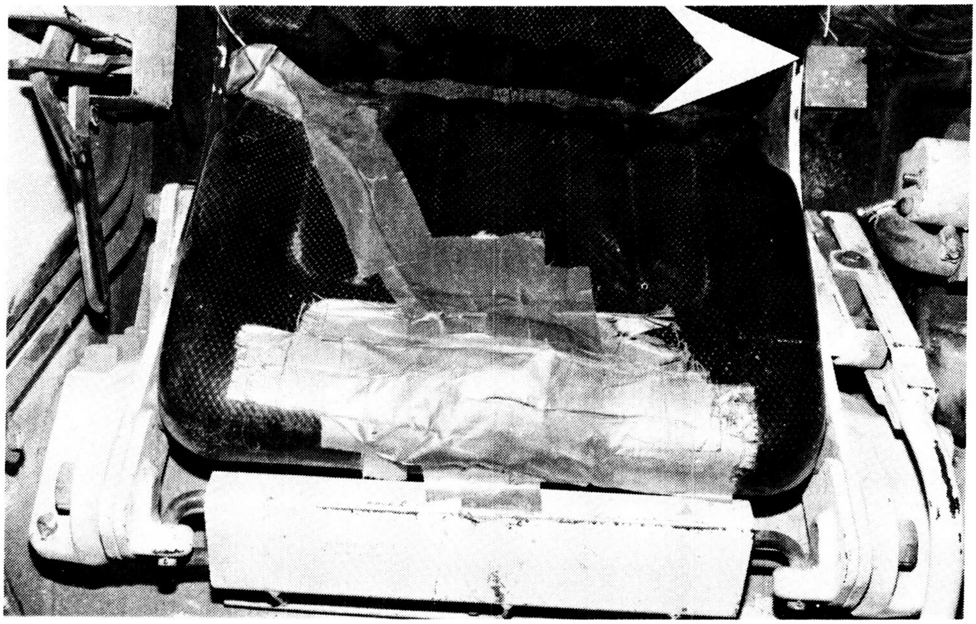

Figure 13. Floor Mounted Accelerometer at Driver Seat

In the design of the vehicle suspensions, it has been found useful to obtain ride quality numbers from sensors located at the center of gravity of the vehicle. Figure 14 shows the CG installation of a single axis accelerometer sensing vertical acceleration and Figure 15 shows a triaxial installation at the CG. In some tests, the three outputs of the triaxial ride numbers are combined and used to obtain an overall ride quality number for absorbed power and ISO rms acceleration.

In addition to the accelerometers at the driver location and the CG packages, an accelerometer is mounted at the roadwheel axle on the roadwheel suspension (road arm) to sense acceleration in the direction perpendicular to the road arm. The sensor complement is completed by roll and pitch gyros located reasonably close to the center of gravity as shown in Figure 15.

In any specific test run of the M1 tank, it is desirable to have ride quality numbers derived from each of the sensors on the vehicle. This is readily accomplished by recording all signals on magnetic tape and subsequently playing them back through the ride meter in the laboratory. In this way, correlations can be made between the ride quality numbers from the various sensors, and this information can be expected to contribute to improved suspension designs as well as to refined measures of crew effectiveness in relation to the vibration environment.

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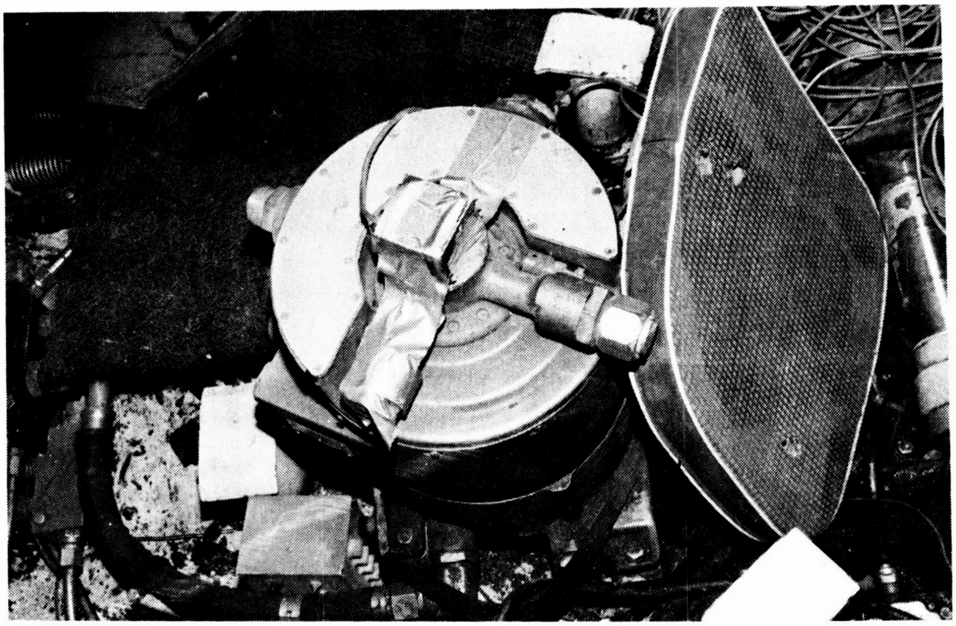

Figure 14. C.G. Vertical Accelerometer

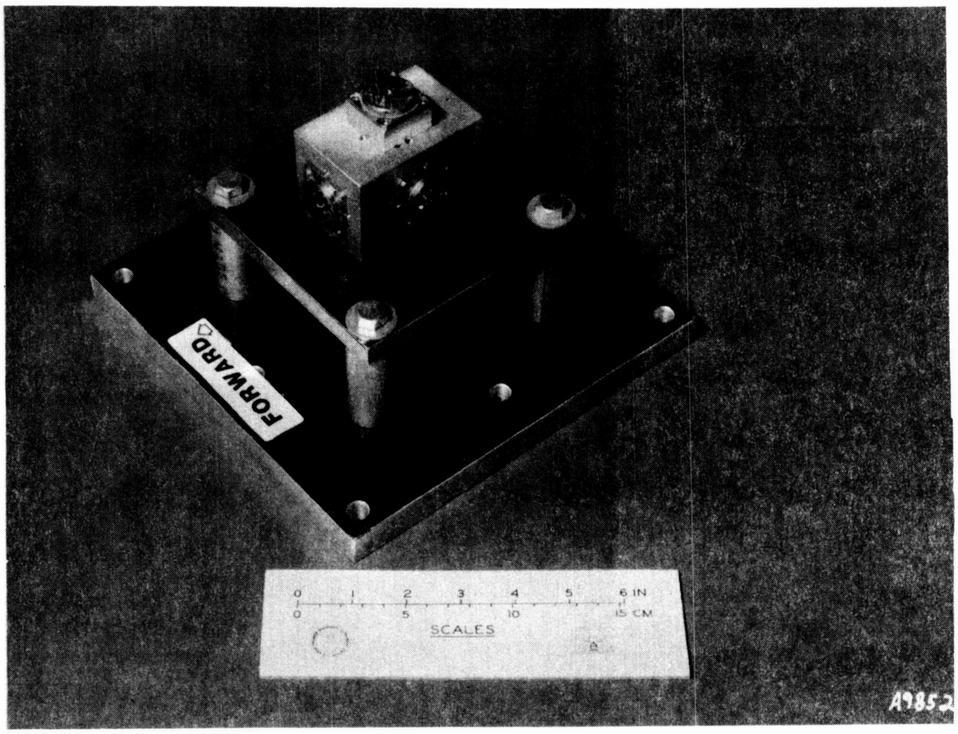

Figure 15. Triaxial Accelerometer Mount for C.G.

Finally, the ride quality numbers will be used to compare the relative merits of two suspension systems designed for the M1. These are the conventional torsion bar suspension (with fluid dampers on road arms 1, 2, and 7), and the hydro-pneumatic suspension. Some indication of the external differences of these suspensions can be found in Figure 16 (torsion bar) and Figure 17 (hydro-pneumatic). A detailed contrast of these two systems will be deferred to a later report after significant comparison testing has been done. For the present, a description of the method of measurement of hull forces on the torsion bar suspension system will be given.

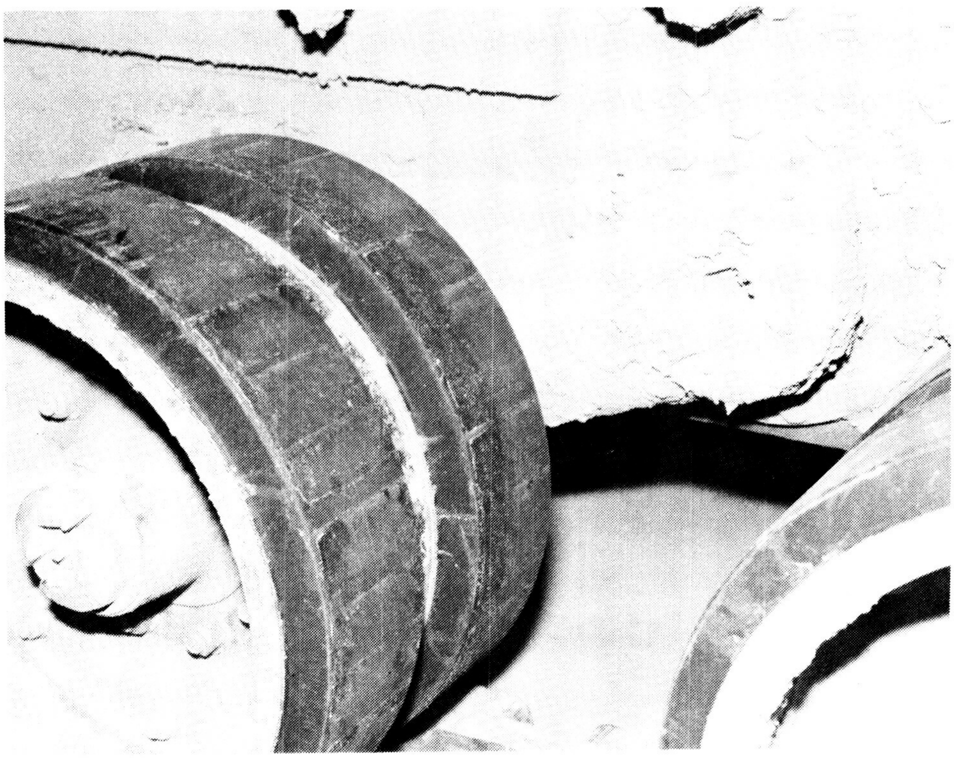

Figure 16. Standard Torsion Bar Suspension

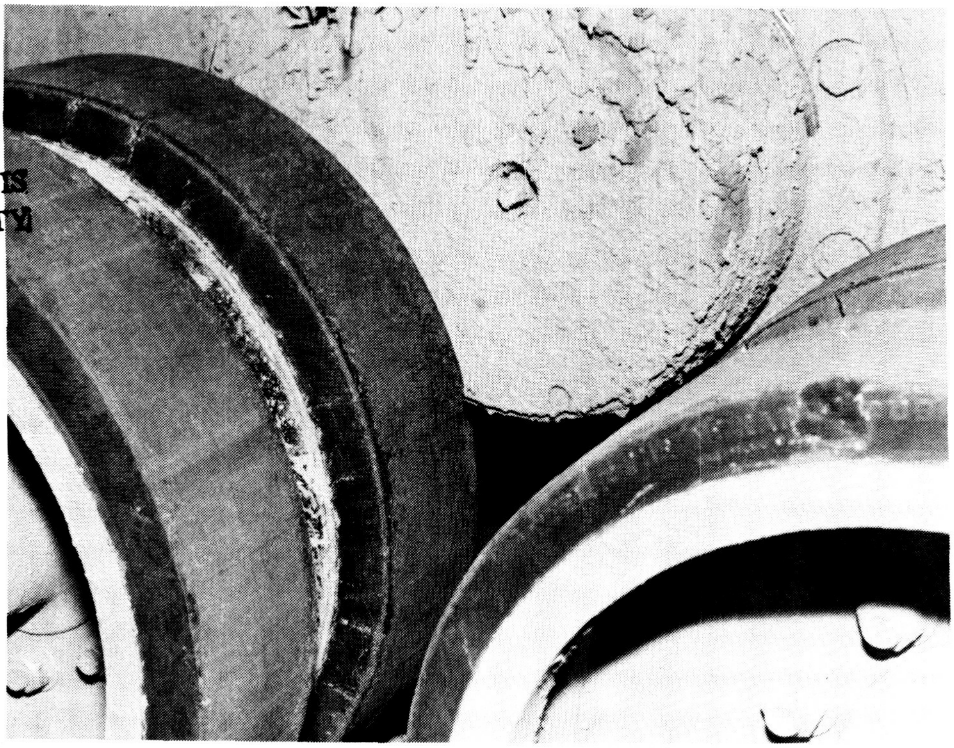

Figure 17. Hydro-pneumatic Suspension

MEASUREMENT OF HULL FORCES

From the preceding discussion, it is clear that the ride meter outputs from the diverse sensor locations will provide a good basis for comparison of the two types of suspension provided for the M1 tank. By the same token, however, the single number indicator does not give any useful information on how the forces of the surroundings are put into the vehicle. A knowledge of these forces is desirable because computer models of the vehicle can take representations of these forces as input and produce, among other things, the ride quality number that is given in an actual test by the ride meter. If the computer model is reliable and the input forces are accurate, various test scenarios can be simulated on the computer instead of actually being carried out in the field. The cost savings of such a procedure are immediately apparent.

To accomplish these purposes, it is necessary to build a data base of hull input forces under various field conditions. The torsion bar suspension design gives rise to input torques as well as input forces at each road arm station, so provision must be made to measure these quantities. These measurements will be made only on the vehicle with torsion bar suspension; there are no present plans to instrument the hydro-pneumatic suspension system.

The M1 tank rides on seven roadwheels per side, numbered 1-7 front to back. The number 1, 2, and 7 roadwheels are supported by torsion bars and fluid dampers, the others are supported only by torsion bars. The design of the suspension is such that only torque is transmittted through the torsion bars, while torque and force (notably, vertical force) are transmitted through the load-carrying elements associated with the damper. Both torque and force are measured with strain gage bridges.

The torsion bar is a thick-walled cylinder approximately 2.5 inches in diameter and 86 inches long which extends from the roadwheel to a point of attachment on the opposite side of the tank. The torsion bridge on this member was placed at a convenient location and presented no special problems. Gaging the rotary damper, however, was somewhat more involved. The road arm is rigidly fixed to a large tubular shaft which is keyed to the rotor of the damper. This same shaft, through bearings, supports the weight of the tank and transmits any other road forces to the hull. In carrying these forces, the shaft behaves as a beam, so that the magnitude of the forces can be measured by gaging the beam in a bending mode. At the same time, an additional bridge is attached to the shaft to sense torque due to the damping force in the rotary shock absorber. Some difficulty was encountered in the force measurement because the angular orientation of the bending gages changed with changing road arm angle, but this problem was resolved with careful laboratory calibration. A photograph of the bending and torsion gage shows their locations on the shaft in Figure 18. Note that the shaft is shown attached to the ride meter road arm through splines. The shaft is also welded to the road arm on the outside face. The splines on the other end of the shaft engage the damper rotor.

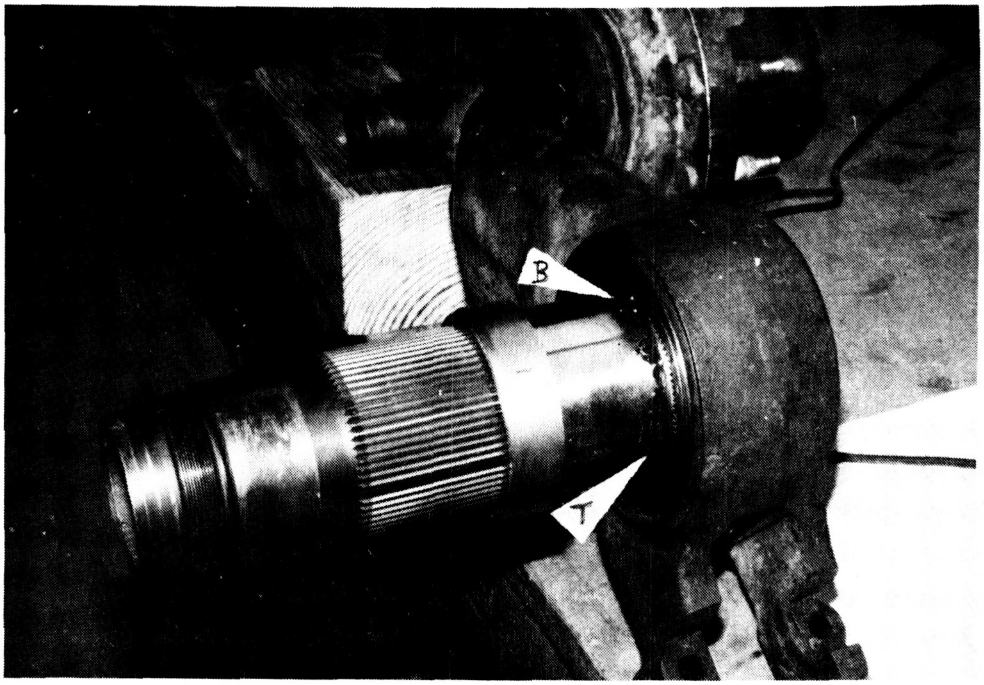

Figure 18. Road Arm Torsion and Bending Strain Gage Locations

Details of the calibration procedures and comparative test data between the two systems will be discussed completely in a later report when sufficient test data for meaningful conclusions will be available. These tests are scheduled for the month of August 1987 but will not be completed in time for inclusion here.

CONCLUSION

Interest in vehicle ride quality and its measurement has been growing steadily over the past two decades. Its importance to the military establishment with its great variety of surface vehicles is obvious, but ride quality is becoming a factor of increasing importance in the transportation industry, to manufacturers of all types of aircraft, farm machinery, earth-moving and construction equipment, and others. At the present time, it cannot be said that there is general satisfaction with commonly used indicators of ride quality, nor is there complete agreement as to the level of vibration, and to the frequency weighting functions which accurately assess limits of operator effectiveness and well being. However, experimental activity in this area is growing, and there will be reliable standards for evaluating the effect of vibrational environment on the human operator. Once this is established, it should be possible to effect significant improvements in suspension design.

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