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DYNAMIC TEST PROGRAM, CONTACT POWER COLLECTION FOR HIGH SPEED TRACKED VEHICLES

C. H. Spenny

APRIL 1973
FINAL REPORT

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16. Abstract

A laboratory test program is defined for determining the dynamic characteristics of a contact power collection system for a high speed tracked vehicle. The use of a hybrid computer in conjunction with hydraulic exciters to simulate the expected dynamic environment is described. A laboratory setup for examining the effects of brush friction is also described.

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Power Collection, High Speed Tracked Vehicles

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PREFACE

The test plan described in this document was developed by the Power and Propulsion Branch at the Transportation Systems Center (TSC) for the Office of Research, Development and Demonstration (ORD&D), Federal Railroad Administration. The purpose of the document is to describe the role of laboratory dynamic testing of power collection systems and to define a test program which evaluates the dynamic characteristics of proposed power collection systems for the high speed tracked vehicle.

This activity is part of a program which provides technical support to ORD&D in the development of the power collection system for the Tracked Air Cushion Research Vehicle.

TABLE OF CONTENTS

Section Page

LIST OF ILLUSTRATIONS

1. INTRODUCTION

This document describes the dynamics test program to be conducted at the Transportation Systems Center (TSC) for the purpose of evaluating power collection concepts for high speed tracked vehicles. This work is being performed for the Federal Railroad Administration, Office of Research, Development, and Demonstration in support of the development program in power and propulsion for the Tracked Air Cushion Research Vehicle (TACRV).

2. PURPOSE OF THE DYNAMICS TESTS

The objective of this test program is twofold. Initial testing will be performed on a spare collector which has been developed for the TACRV. This testing will supplement that performed by the contractor who developed the system. It will provide added assurance of successful operation when the collector is installed on the TACRV. At the same time, it will provide a test specimen with which to develop a laboratory procedure for accurately predicting collector dynamic performance.

Subsequently, evaluation of other collector concepts will be performed in order to determine the merits of each. This testing will provide the knowledge required to improve the TACRV design, making it feasible for revenue operation. There are many factors which require further attention such as switching capability and automatic retraction, optimum rail and brush materials, reduced cost of per mile hardware, and improvement in safety and aesthetics. Whether the concept which contains these refinements is active or passive, captive or noncaptive, contacting or noncontacting, cannot be determined without further testing.

While the purpose for a research vehicle such as the TACRV is to provide a test bed for developing hardware beyond the state of the art, failure of a crucial subsystem such as the power collector during initial demonstration is not acceptable. For this reason, considerable testing has been performed by the contractor to verify collector performance. This has included a demonstration of operability at the design speed of 300 miles per hour on a 1500 feet section of power rail which was installed adjacent to a rocket sled track.

Satisfactory performance of this test provides considerable assurance that the collector will perform satisfactorily on the test track at Pueblo. However, there are several limitations to this type of testing. For example: many individual disturbances and influences which degrade performance are difficult to isolate; critical parameters may go unmonitored throughout the test program because the system cannot be observed during test runs or because the required instrumentation cannot be operated from the moving vehicle; tests cannot be duplicated with sufficient accuracy on a track to substantiate results-due to changes in environmental conditions, due to the inability to achieve identical sled speed, and due to the operating problems of schedule and cost which limit the number of runs; and the ability to make parametric variations and to acquire reliability data is limited by the slow accumulation run time and by the fear of catastrophic failure.

Dynamic tests performed in the laboratory serve to complement and enlarge upon the knowledge of collector behavior acquired with the sled test by permitting isolation and interpretation of individual influences affecting the system, visual observation and adjustment all critical parameters, repetitive testing for verification of results, and extended tests to determine reliability.

Evaluation of alternate collector concepts by constructing short sections of power rail at a sled test facility would be costly and time consuming. Laboratory evaluation is cost effective for this purpose since only on-board hardware is required. Likewise failures do not destroy rail equipment. The technique developed for testing the TACRV collector will permit effective evaluation of alternate collectors in the laboratory.

3. TEST APPARATUS

Evaluation of collector dynamics in the laboratory is similar to evaluation of vehicle dynamics in the laboratory.[1] The test concept is based upon the use of a rail substitute system. Since there is no way of precisely implementing long sections of power rail, the dynamic response of the power rails in the lateral directions is simulated. The only part of the power rail that is duplicated materially is a section required to support the collector. The rail substitute is then part of the test apparatus (e.g. a short piece of rail mounted on an actuator) and the collector is the object under test.

The mechanism for imparting lateral rail motions can be as simple as a single actuator which imparts motion to one or more of the brushes of the collector. At the other extreme, it can consist of an elaborate set of cam rollers that impart a fixed amplitude at each brush location, properly sequenced to correlate with collector velocity.

The simpler concept, as shown in Figure 1, has been adopted by the contractor to perform laboratory testing of the TACRV collector. In this case the actuator is an electromagnetic exciter. The collector is supported by a rigid vibration fixture mounted on the actuator which consists of short segments of power rail. A second fixture is also used which vibrates one of the three power rails while the others remains fixed. The exciter produces sinusoidal motion with amplitudes and frequencies corresponding to levels anticipated due to rail irregularities and brush dynamics. The limitations of such a test apparatus are the inability 1) to drive the exciter with rail deflection data and 2) to separately and simultaneously excite each brush location.

The mechanism shown in Figure 2 is an example of a cam system which excites individual brushes on a captive collector. The number of cams required is equal to twice the number of individual brushes on the collector, so that rail motion in two orthogonal directions can be imparted. Drawbacks of the single exciter system

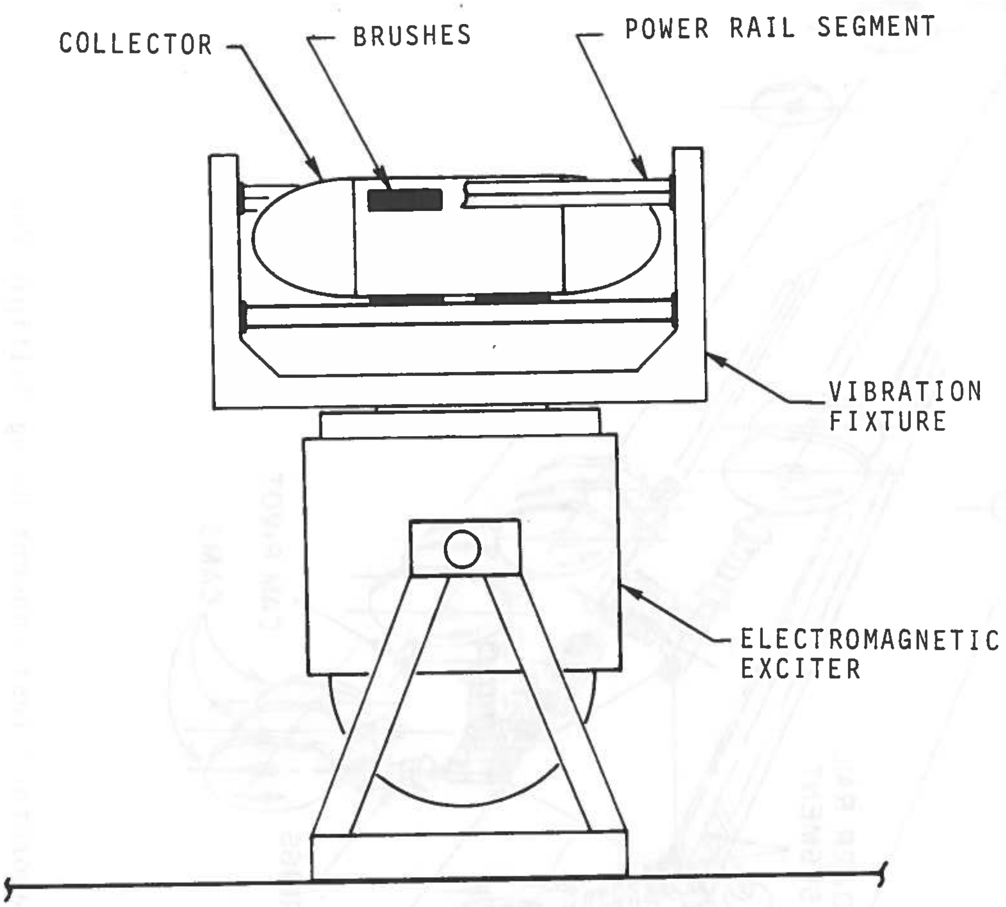

Figure 1. Laboratory Test Concept for TACRV Collector Dynamics

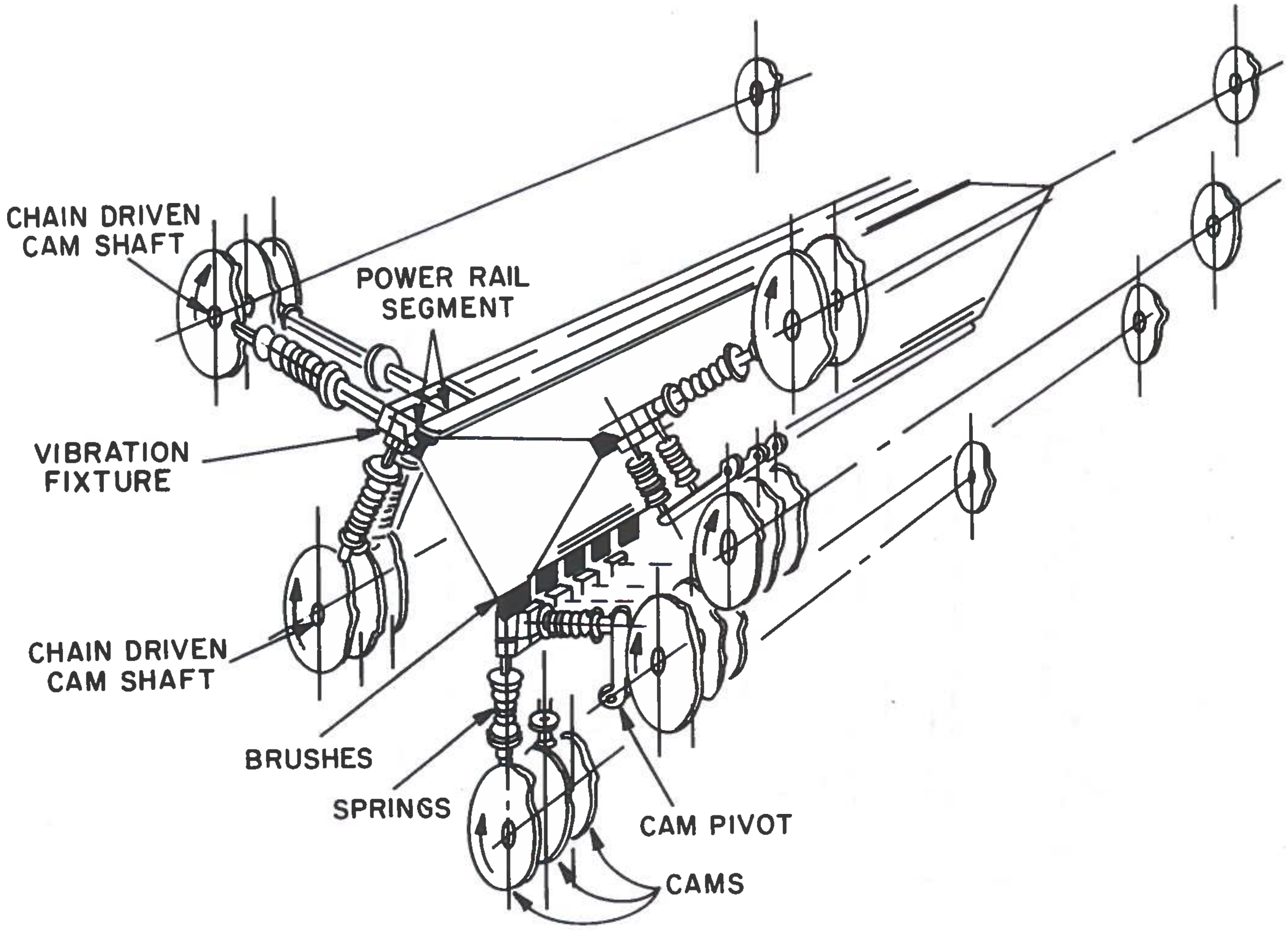

Figure 2. Laboratory Test Concept Using Multiple Cams

are eliminated, but the flexibility of this system is severely limited by the necessity for changing cams for each type of rail fault and changing the entire fixture for testing different rail configurations.

The test bed set up at the TSC, as shown in Figure 3, eliminates the drawbacks of each of the previous concepts. Six hydraulic actuators are shown, one at each of the six brush cluster locations. The actuators are capable of separate excitation from any external source with frequencies down to DC so that rail deflection data as recorded from computer simulation or actual rail measurements can be used. Appendix A gives the performance capability of the hydraulic system and Figure 4 shows a single actuator set up to impart lateral rail motions to a conventional third rail collector.

Six head excitation is sufficient for simulating TACRV collector motions since rail configuration is such that only deflections in one lateral direction are significant. Additional actuators will be required for testing rail configurations which have significant motions in two lateral directions. Likewise additional actuators would be required to examine individual brush behavior in each cluster simultaneously. However, preliminary testing may indicate that certain clusters can be held fixed and those actuators relocated to excite individual brushes of a single cluster.

To change the configuration for testing other collectors requires only that a different set of mounting brackets be made up to relocate the hydraulic actuators.

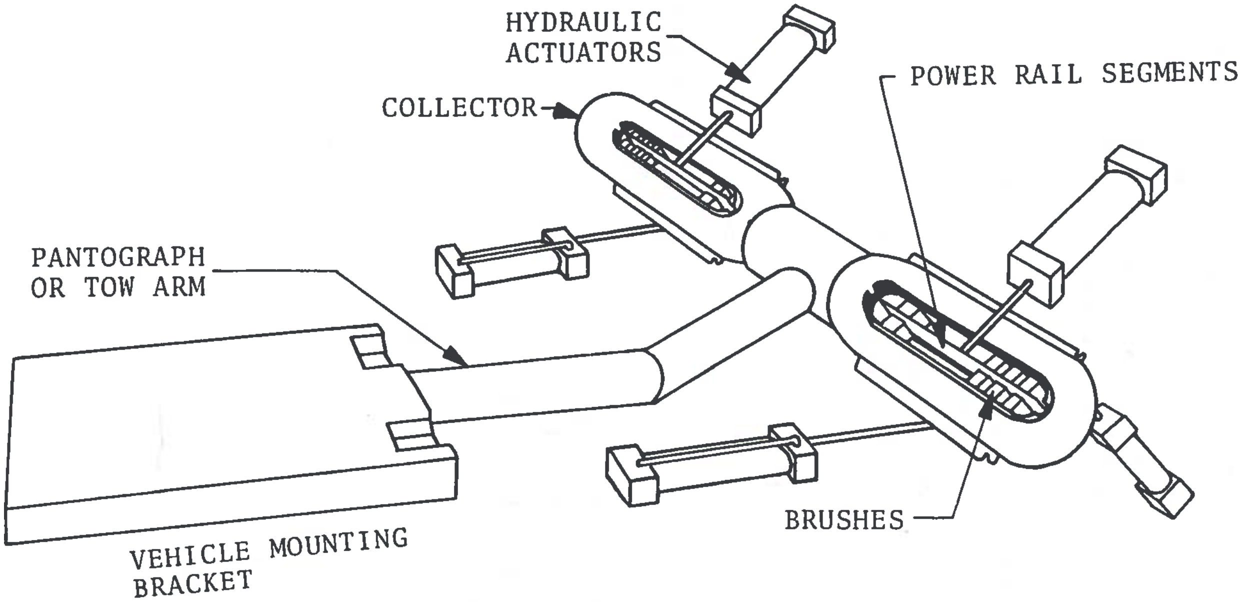

Figure 3. Laboratory Test Concept Using Hydraulic Actuators at each Brush Cluster

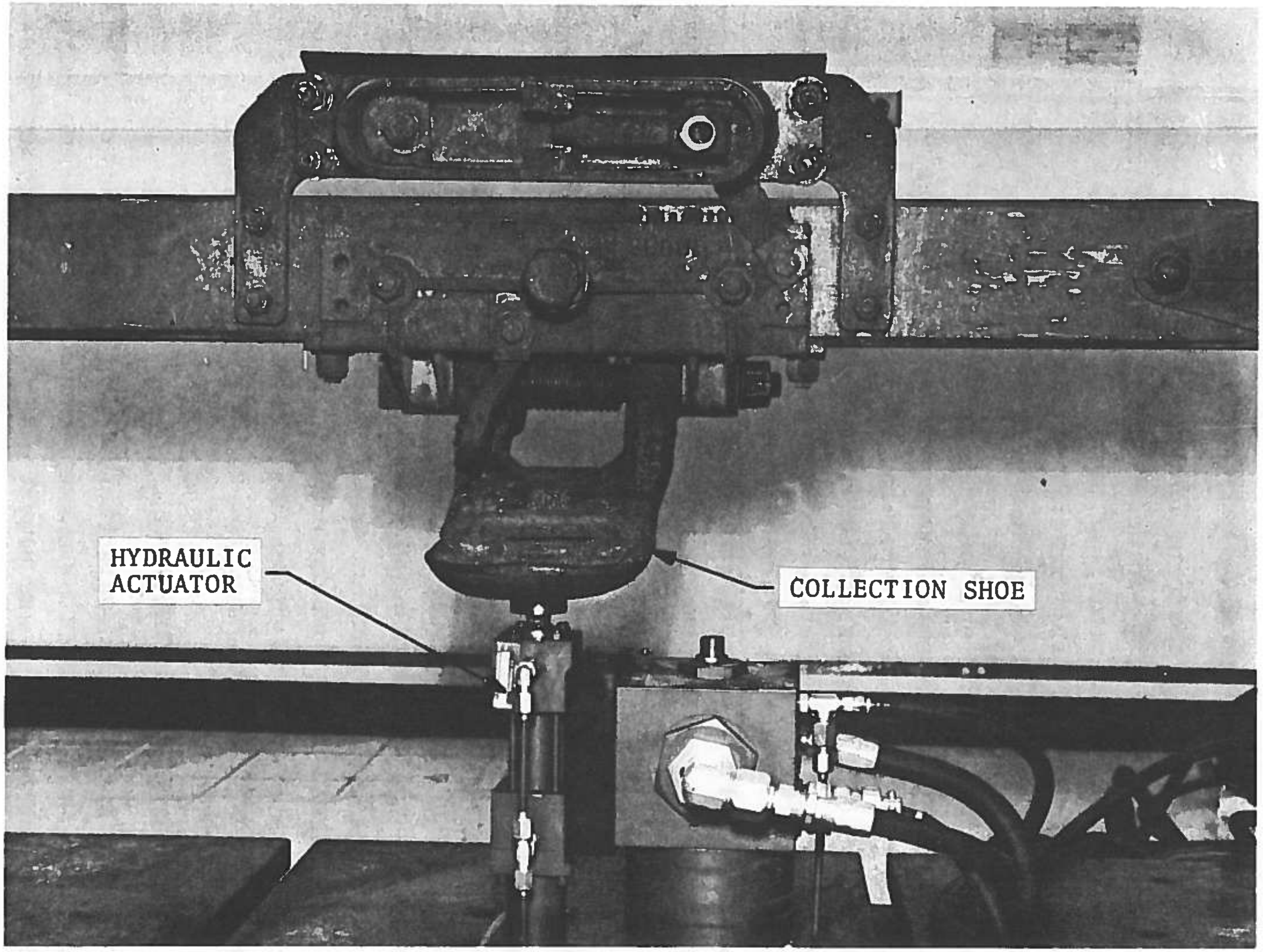

Figure 4. Dynamic Excitation of Conventional Third-Rail Collector.

4. TEST PLAN (TACRV COLLECTOR)

True collector response is measured only when collector-rail interaction is permitted to occur. To demonstrate this interaction in the laboratory the actuator input must be controlled with a closed loop signal that adjusts rail motions to the varying dynamic load of the collector as shown in Figure 5.

The objective of the test program at TSC is to develop a closed loop test to evaluate dynamic interaction between the collector and rail. However, the results of open loop testing as shown in Figure 6, which is a first step toward this goal, will be useful in assessing TACRV collector performance. With this in mind, initial testing will be open loop. Closed loop simulation and the evaluation of alternate collector concepts will then be performed as part of the ongoing research.

4.1 SINUSOIDAL VIBRATION TESTING

Sinusoidal motion will be imparted at each of the six brush clusters in the combinations and with the phases required to excite the rigid body and fundamental flexible body modes of the collector. Natural frequency, mode shape and frequency response data will be determined by monitoring accelerometer outputs mounted on the collector. This data will be used in developing an accurate analytic model of the collector to be used for parametric studies and for developing transfer functions required for closed loop testing.

4.2 RESPONSE TO RAIL IRREGULARITIES

Computer simulation of rail displacement for various types of irregularities such as sagging rail or unsupported collector weight will be recorded on magnetic tape and played into the actuators at each brush cluster. A strobe light will be used to examine all brush and collector motions with particular emphasis on brush bounce. As it becomes available, other data on rail displacement from the

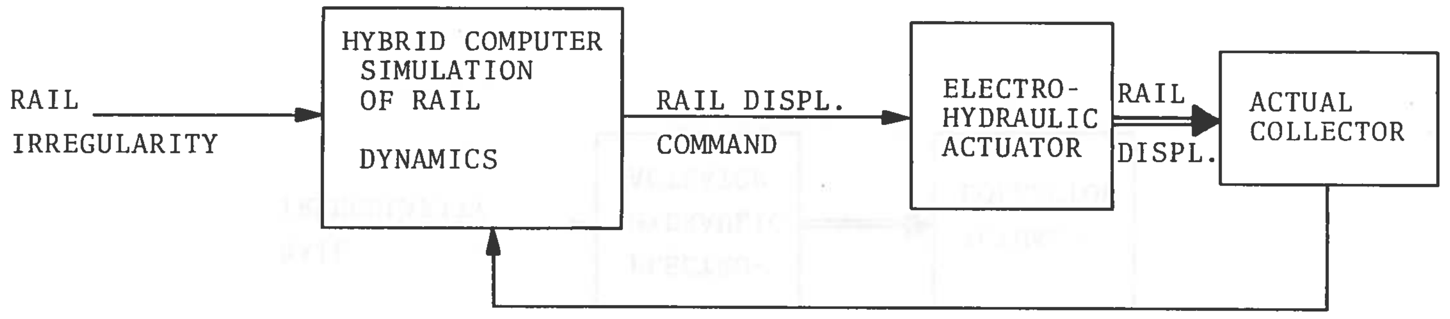

Figure 5. Control Concept for Demonstrating Collector-Rail Interaction

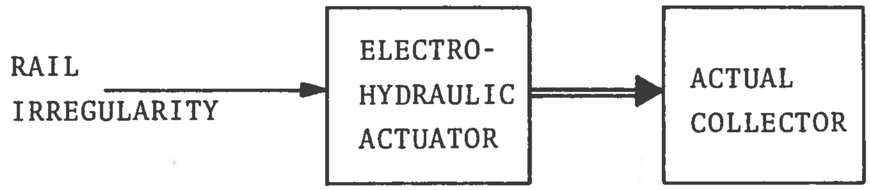

Figure 6. Open Loop Testing of Power Collector Dynamics

rocket sled tests and Pueblo instrumentation will be recorded or formulated on a wave synthesizer to drive the actuators.

4.3 TUNING OF COLLECTOR PARAMETERS

Parameters which are known to be variable in the TACRV collector are cleaner brush preload, cleaner brush damping, and current brush preload. From the standpoint of drag and friction brush wear, these parameters should be minimized. However, brush bounce should also be minimized. Initially, each brush cluster will be excited as a unit with varying preload and damping to determine the optimum brush pressure and damping. Then, four actuators will be moved to a single cluster of brushes to excite the three pairs of current carrying brushes and one pair of cleaner brushes. An optical displacement transducer will be used to monitor brush motion, since accelerometers mounted on the brushes would alter brush mass and invalidate the tuning. If these tests reveal the need to make physical changes in the collector such as changing spring rates, permission will be sought through the sponsor.

4.4 RESPONSE TO VEHICLE MOTION

A fixture will be built to permit linear and angular vibrations to be imparted to the tow arm base with a hydraulic actuator while the collector is held in a rail type fixture. This will simulate vehicle induced vibration. The collector and brushes will be monitored to determine their response characteristics.

4.5 FATIGUE TESTING

Vibration for extended periods of time will be conducted with the collector fixtured as described in Section 4.4 above. The amplitude of the input signal will be nominal. The objective is to assure that no components in the collector or tow arm are operating above their fatigue strength. Following this test, the collector will again be mounted in the fixtures used for tests in Sections 4.1 and 4.2 above and the fatigue testing continued.

4.6 COLLECTOR-RAIL INTERACTION

The objective of this test is laboratory demonstration and examination of collector-rail interaction. Demonstration can be accomplished using the simple control scheme shown in Figure 5 where the rail simulation is performed on a computer and fed to the hydraulic actuator system, hence imparting motions to an actual collector. Displacement (or acceleration) of the collector is fed back to the simulation for computation of the effect on rail motion under the collector. An on-off switch in the feedback line to the simulation will be used to demonstrate the effect of interaction.

Accuracy of this control concept is limited by the performance capability of the actuator system and computer. Ideally the transfer function of the actuator should be one and the phase lag should be zero since that hardware is not part of an operational collector system. Hydraulic actuators to be used for this testing have a feedback compensation network which can be adjusted for less than 3 dB of gain loss and less than 30° of phase lag up to 100 Hz. The test facility has been located adjacent to the hybrid computer facility to minimize transmission line losses (as well as facilitate control of the experiment). This capability assures that interaction can be demonstrated.

A more accurate control concept is required for examination of he details of the interaction problem. As a rule of thumb the apability of the actuator should be an order of magnitude higher n response capability than the system being studied. As a minimum, he first and second mode of rail deflection should be included in he study. The second mode oscillation of the TACRV power rail is n the 80-100 Hz range which is of the same order of magnitude as he capability of the actuator system. Thus, a control scheme with daptive-inverse compensation as shown in Figure 7 is required to mprove the actuator capability. This transfer function is developed n the hybrid computer, necessitating additional transmission lines

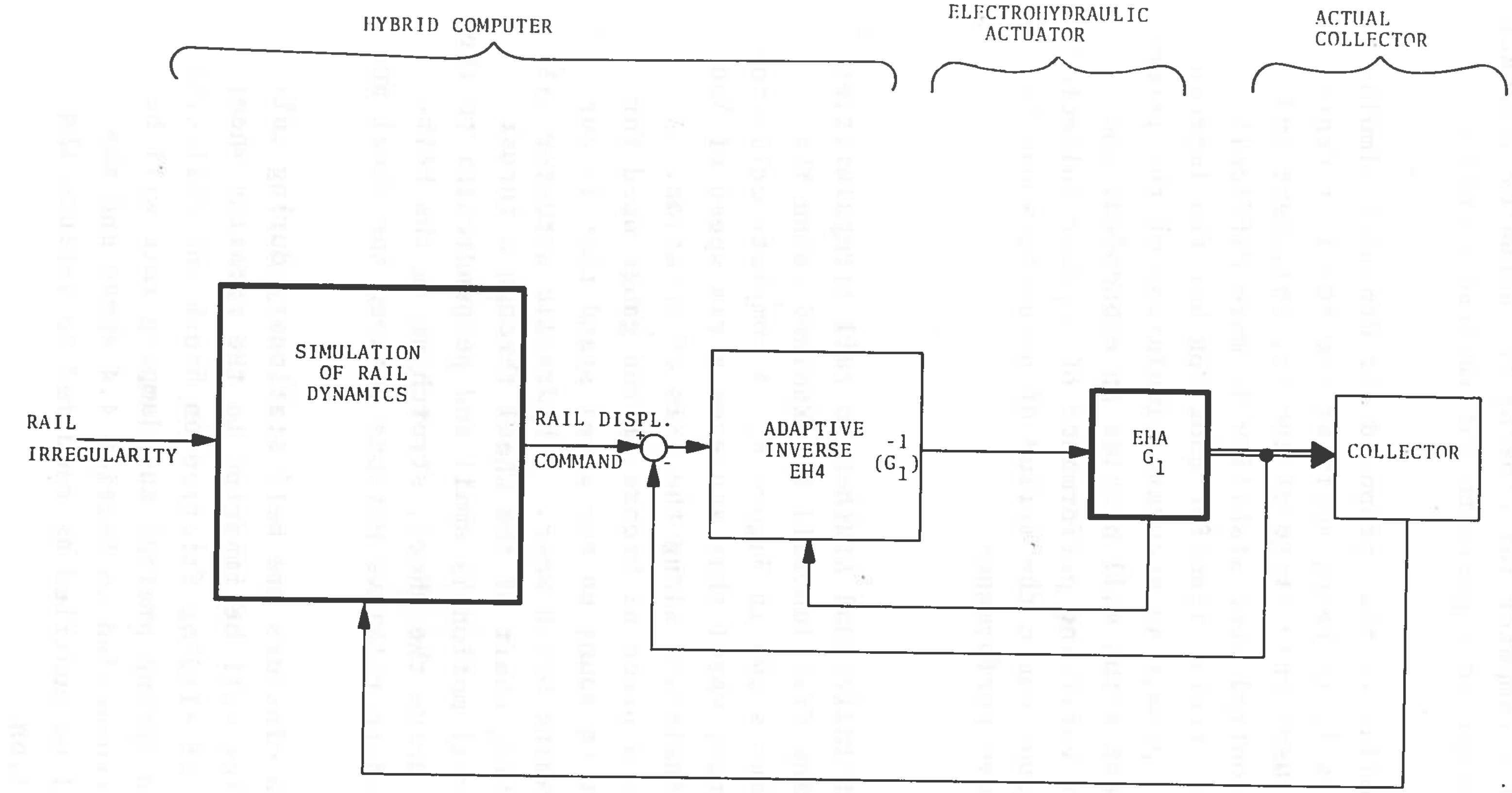

Figure 7. Adaptive Control Concept for Closed Loop Testing of Collector-Rail Interaction

from the test setup to the computer for closing the actuator feedback loop and supplying the adaptive signals to the inverse transfer function.

This concept is similar to that proposed for dynamics simulation in the wheel-rail facility being built at the FRA Test Center in Pueblo, Colorado and uses only state-of-the-art equipment and techniques. Achieving control loop stability is more difficult with the addition of the inverse transfer function but the improvement in performance will permit an accurate simulation of the interaction problem. This test setup will provide an economical and nondestructive means for verifying performance of a power collector under laboratory conditions where the myriad of parameters may be varied in order to improve performance.

4.7 BRUSH DYNAMICS

Lateral response of individual brushes to rail irregularities in the presence of sliding friction will be examined using the configuration of equipment shown in Figure 8. A complete collector is mounted above a rotating wheel that achieves a rim speed of 300 miles per hour while translating along the axis of rotation. A wheel whose periphery is a piece of bronze of the gauge used for power rail will be built to mount on the wheel stand that is currently being used to examine brush wear. A hydraulic actuator will be attached to the rotating shaft of the wheel through a thrust bearing. Because the axial motion is small and perpendicular to the plane of the belts that drive the wheel, stretching in the belts is sufficient to accommodate relative motions between the wheel and motor.

The remaining brush clusters are held stationary during this test. Rail irregularities will be imparted to the rotating wheel to determine the effect of sliding friction on brush and collector dynamics. Variations in spring preload and damping rate will be tried to update those recommended in Section 4.4 above and the computer simulation will be modified as required to include the effects of sliding friction.

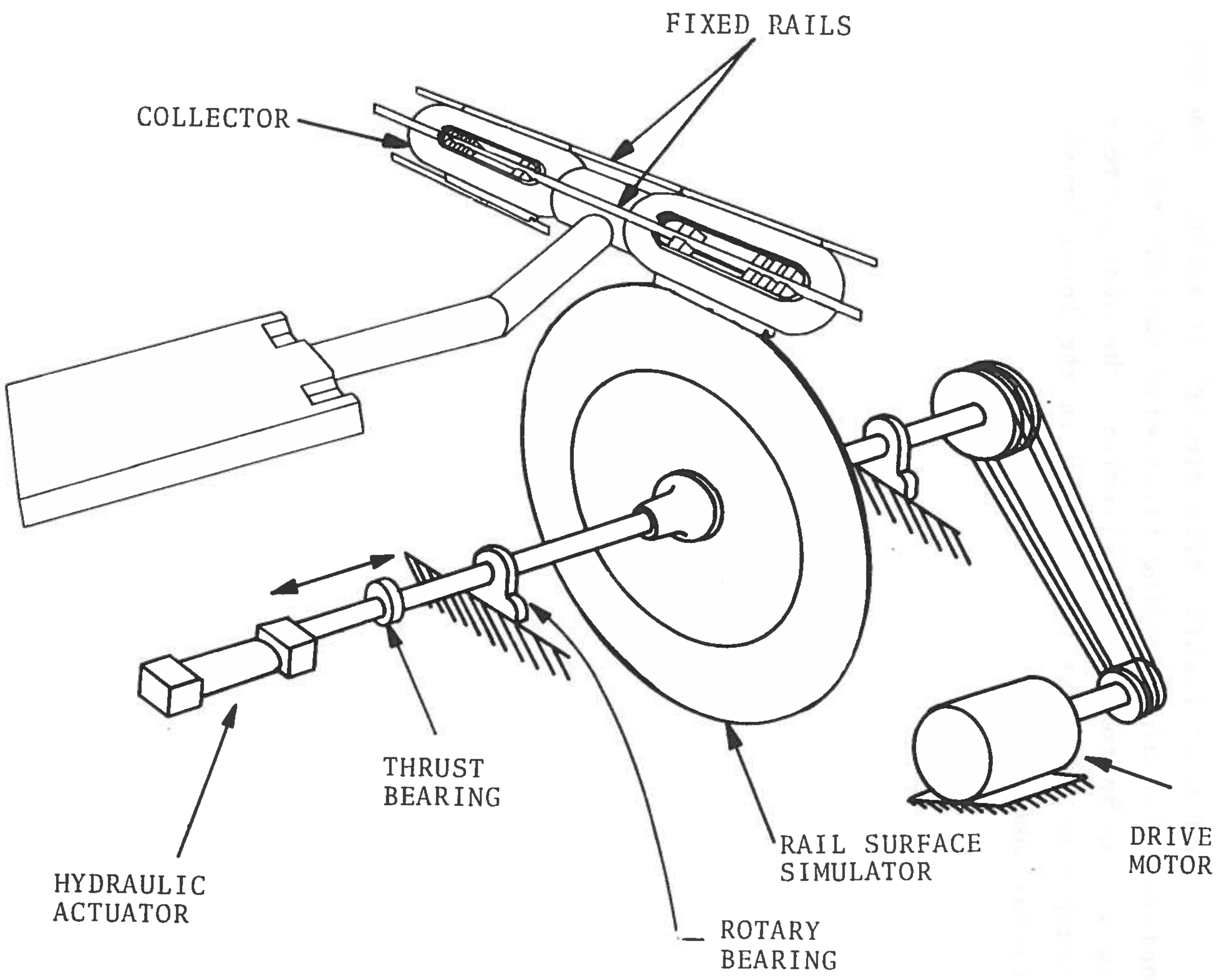

Figure 8. Test Configuration for Evaluating Brush Dynamics

Rail irregularities and vehicle induced loads will be imparted simultaneously to determine the brush wear pattern. Alternate brush-holder techniques will be tried if the brushes wear unevenly or become rounded. Rated current will be conducted during this test since part of the brush wear results from electrical arcing. Because the wheel is only capable of imparting transverse motions to the brushes located at the bottom of the collector, the wear pattern on the upper brush clusters must be examined in the lower brush set with artificial loading.

5. TESTING OF ALTERNATE CONTACT COLLECTORS

Other concepts capable of collecting three phase power are now being developed in Europe by Tracked Hovercraft, Limited, and LeMoteur Lineare. These are shown in Figures 9 and 10 respectively. Tests similar to those described in the previous section will be performed using prototypes of these concepts to determine their capability at 300 mph. Likewise, an active system as shown in Figure 11 will be tested. This concept is attractive because it has the capability for high speed switching.

Laboratory demonstration of an active system will be accomplished by using three hydraulic actuators as shown in Figure 12. The actuato head on the right represents the vehicle. These hydraulic actuators are driven by servovalves in the displacement feedback mode to faithfully reproduce rail and vehicle lateral motions respectively. The center actuator represents the collector. It is rigidly attached to the right hand actuator head (the vehicle). The head of the center actuator represents the brush.

The principle of operation of the "active collector" is to maintain constant pressure against the rail while the rail and vehicle are moving laterally. The key to successful operation is a sensor with the required response characteristics that can withstand the severe environment. In Figure 12 the sensor is a pressure transducer in the hydraulic servovalve. Other possibilities that are more sensitive but not so durable such as optical and capacitance transducers will also be tried. The objective will be to demonstrate an active system capable of operation at 300 mph.

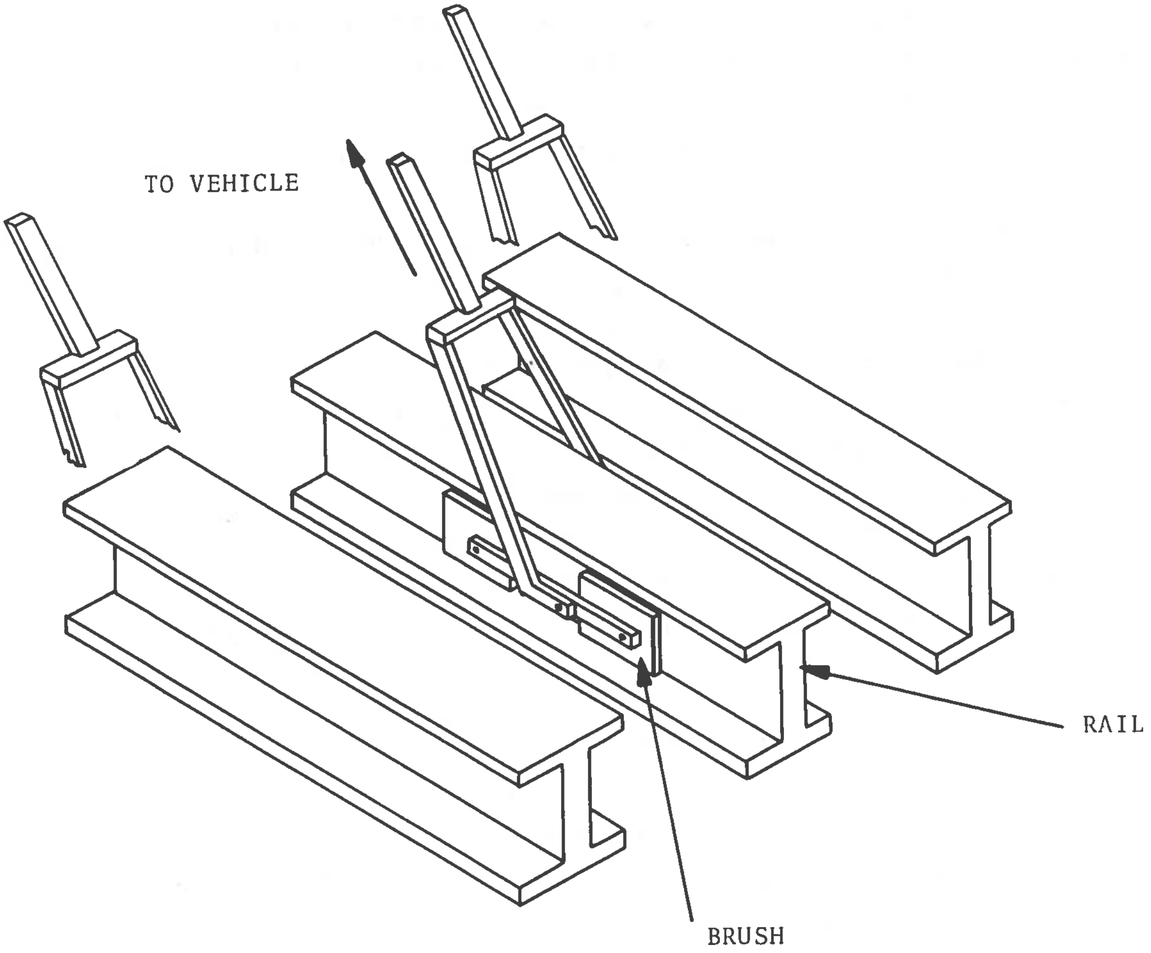

Figure 9. Collector Concept for Tracked Hovercraft, Ltd. TACRV

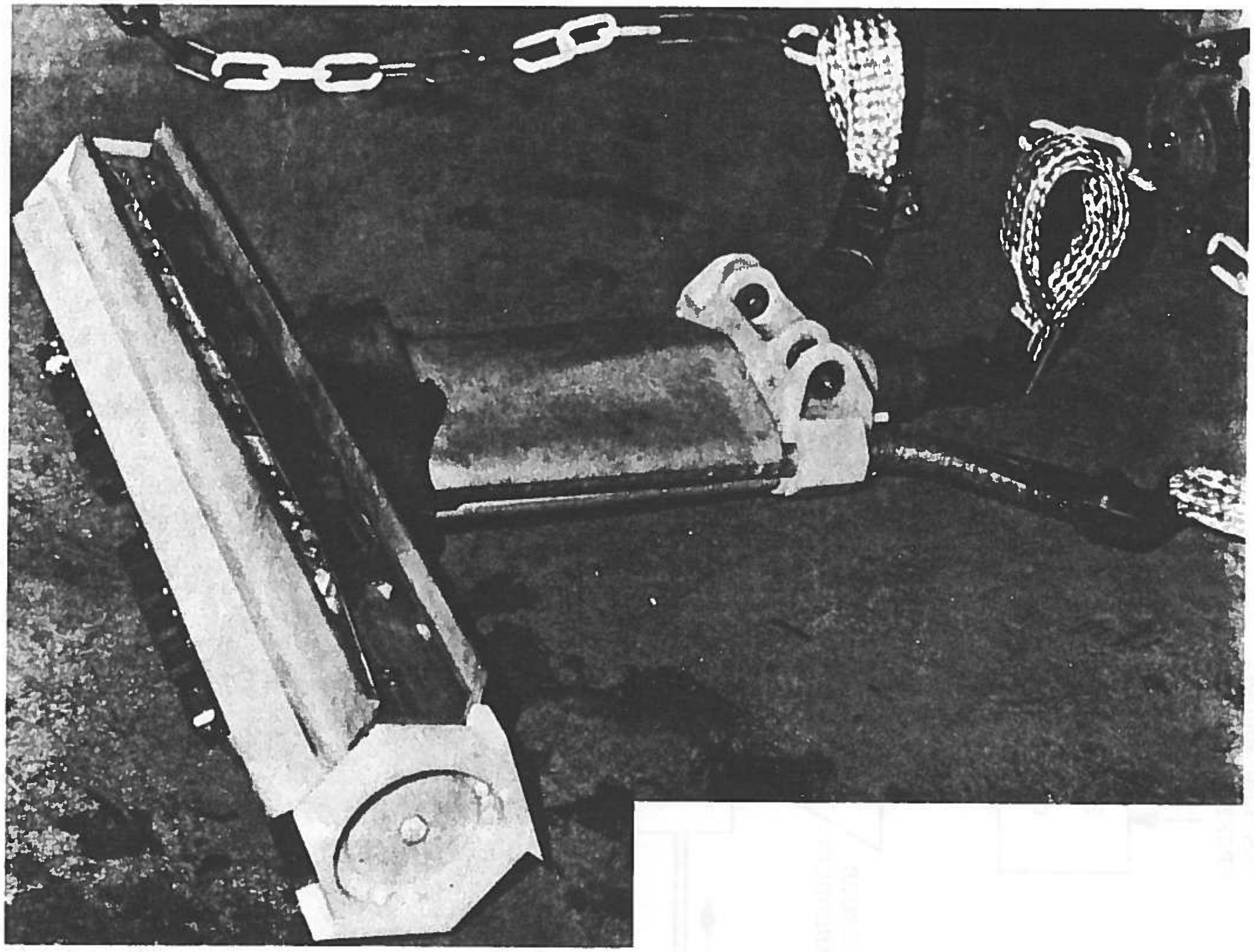

Figure 10. Collector used for French Aerotrain and U.S. Urban TRACV

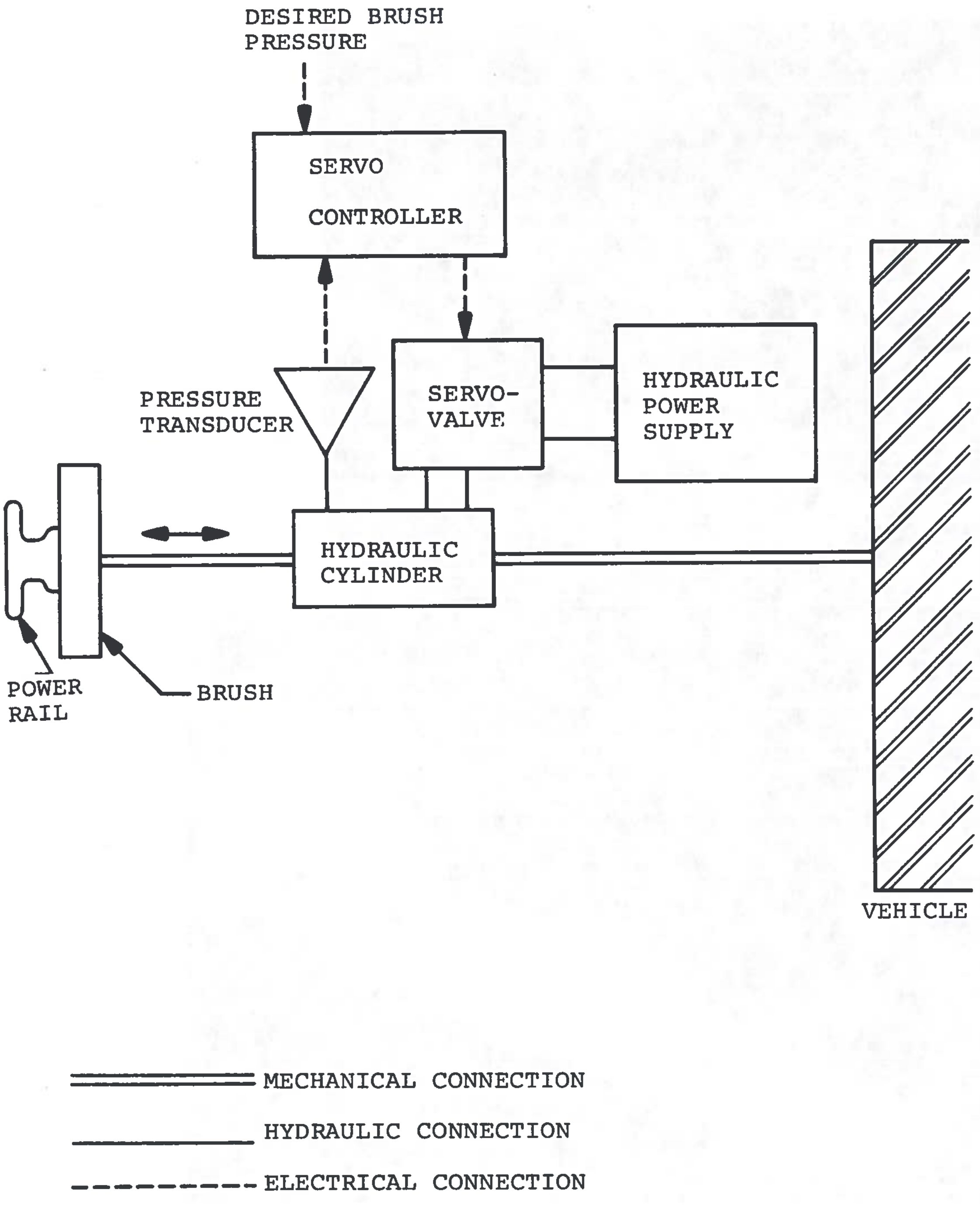

Figure 11. Typical Active Collector

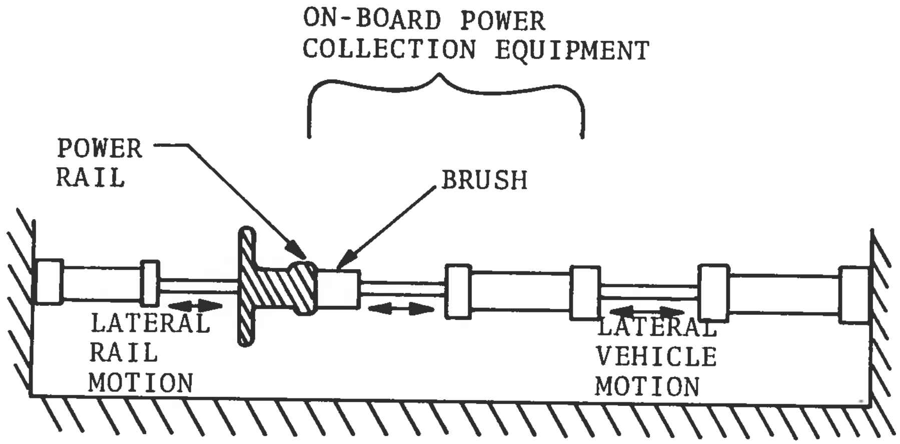

Figure 12. Actuator Configuration for Laboratory Demonstration of an Active Power Collection System.

REFERENCES

1. Milenkovic, V., et al, "Feasibility Study for Wheel-Rail Dynamics Research Facility," General American Research Division, PB 182 472.

APPENDIX - ELECTROHYDRAULIC SHAKER

SYSTEM TECHNICAL DATA SHEET

A.	Exciter Force Rating:	400 lbs @ 1500 psi supply
B.	Exciter Stroke Rating:	2 in double amplitude
C.	System Velocity Rating for One Exciter:	63 in/sec
D.	Flow Required, Average:	5 gpm
E.	System Velocity Rating for Two Exciters:	63 in/sec
F.	Flow Required, Average:	10 gpm
G.	System Operating Pressures:	1500 psi supply 150 psi return
H.	Servo Valve Flow Rating at 1250 Psi Valve Drop:	5.5 gpm to 500Hz
I.	Accumulator Precharge:	2/3 operating pressures <u>Supply</u> <u>Return</u> 1000 psi 100 psi
J.	Hydraulic Power Supply Rating:	14 gpm @ 1500 psi
K.	Drive Motor Operating Voltage:	460v, 3Ø, 60Hz
L.	Power Required, Total System:	20kva @ 460v, 3Ø, 60Hz, 25 amps
M.	Cooling Water Required:	7 gpm @ 80°F max
N.	Hydraulic Fluid:	Petroleum base, 100-200 SSU @ 100°F American Oil Co. All Weather Hydraulic Fluid
O.	Control Console Operating Voltage: (This is available from step-down transformer in hydraulic power supply cabinet.)	115v, 1Ø, 60Hz