ASTM SKID TRAILERS
INSTRUMENTATION SYSTEMS THRU COMPUTERIZATION

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This paper deals with the configuration and instrumentation of passenger tire skid trailers. While topics written in the past have dealt mainly with testing techniques, geometry, water flow, contamination, surface descriptions, speed, rate of braking, length of skid, etc., this paper addresses itself primarily to Instrumentation Systems. Over the past twenty years, instrumentation systems have changed from vacuum tube amplifiers to solid state; from pen recorders to light beam and fiber optic oscillographs to digital tape, etc. The authors also describe a new approach to the acquisition of skid data by installing programmable calculators or mini-computers with the proper digital Interfaces to sample the analog data. Peak and SN's are then calculated directly from the sampled data. The advantages of Digital Integration over conventional analog techniques are reviewed. Stored data can be recalled, processed and later used to draw Horizontal and Vertical Force Curves, Speed and Percent Slip each Vs. time in addition to Mu-Slip.

In order to conserve time, the authors have decided to primarily address their attention only to Instrumentation Systems in use from approximately 1958 to 1976. According to the records, several skid trailers were in use prior to 1958 and into the early 1960's which used Hydraulic Cells for measuring force. They were interfaced with gage readouts, or pressure transducers and appropriate signal conditioning for use with various types of recorders. One of the most popular recorders at that time was a pen type oscillograph. In addition to recording Horizontal Force it also recorded speed in many instances. A few people were recording Slip, but very little was being done to Mu-Slip data by anyone other than the Air Force.

The earliest reference we could find to the use of Strain Gages for measuring braking force was on a two wheeled skid trailer, very much like the present ASTM trailer which was in use by the state of California in 1949. "Water was pumped from the holding tanks to the spray nozzles located in line and directly in front of each trailer wheel. The brakes were applied on only one trailer wheel at a time. The maximum braking force at each test speed was measured with an SR-4 Strain Gage Dynamometer and a magnetic type direct-inking oscillograph"(1).

Several of the early Skid Trailers did not use any methods of recording the variations in vertical loading while running as many do today. At the time no standards of any type existed, so the measurement of horizontal pull, whether through one or two wheels was divided by the dead weight per tire (tires) to determine the coefficient or SN.

Each company, individual states or agencies had their own ideas as to what constituted a Standard or Reference Tire. By 1958 everyone recognized the need for a reliable Standard tire which would give them better repeatability than a production tire. The birth of the Standard ASTM tire for Traction Testing is considered by many to be the single greatest contribution to have come out of the First International Skid Prevention Conference. Without it, there would not be any reason to substantiate the very accurate digital Instrumentation Systems which are beginning to show up in various forms today.

For the past several years there have been two basic types of ASTM Skid Trailers in use. Perhaps the most universal one utilizes the torque tube principle. This type had and still has rather wide acceptance by users whose primary interest is in the grading of highways and paving materials.

Twenty years ago some of these trailers were using a simple application of SR4 Strain Gages mounted on the top and on the bottom of various torque tube designs. Others used strain gaged links, bars or short cantelever beams built into the basic trailer. At least one unique skid trailer used a Differential Transformer Type of load cell. A GM Trailer at one time had strain gaged brake anchor pins.

Today special torque transducers are in wide use which do a much better job of compensating for temperature and modulus changes, but such transducers do not take into account the inertia change of the trailer configuration and it is still necessary to correct dead weight load by the hitch height to wheel base length in relation to the measured horizontal force to determine a universal SN coefficient.

The tire manufacturers, however, have long preferred to use skid trailers using an X-Y Transducer in each wheel, since this eliminates the h/L factor and takes into consideration the shift in footprint of the skidding test tire. The commentary which follows is largely addressed to skid trailers of this type, but it is also applicable in part to Torque-type transducers.

Specifications

Before discussing typical Instrumentation Systems in detail, we thought it would be of interest to examine two U.S. Specifications to see how they compare, in so far as Instrumentation Tolerances and Timing Sequences are concerned. Each is now undergoing some revisions which may have occurred at the time this paper is presented. It is hoped that revisions which are being considered will bring them into even closer agreement. Table 1 summarizes these specifications.

Typical Instrumentation Systems

Analog Instrumentation

One of the simplest systems in use today has been used for many years and is shown in Figure 1. Horizontal Force signals may be derived by either the torque method or via an X-Y Transducer. Obviously, if the latter is used, provisions for recording the Vertical Force is always supplied.

Speed information can be obtained via a precalibrated towing vehicle or by a fifth wheel.

Signal conditioning has varied widely through the years and still does. An attempt has been made by ASTM, SAE and NHTSA to standardize filtering techniques, but they have not gone far enough. This will be covered in more detail under Section IV comments.

As recent as 3 or 4 years ago it was not uncommon to hang a resistor and capacitor across a signal line until the test engineer and technicians felt the plotted curves "looked smooth enough" while still leaving enough pen movement to show what they thought were reasonable peaks and valleys. This methodology was not wrong as long as it was used for comparative or grading purposes within a company or single agency. It also was not too bad as long as only Slide forces were being used and compared to other trailer results, since Slide SN's were always measured over a period of at least one second. However, if Peak values and Slopes were to be examined, the necessity of some filter standardization was necessary. Both ASTM and SAE, as seen from the tabulation in Section II, established recommended values. The published values appear to be on the verge of being changed either to 0-10 H_z or 0-20 H_z. Note that no recommendations are made regarding the built-in input filtering found in some recorders which should not be disregarded.

Excitation of the force transducers used to be via batteries monitored by a sensitive voltmeter and potentiometer. Today solid state voltage regulators are used.

The Signal Conditioning at times has amounted to nothing more than a Bridge Balance and Span Circuit, the output of which is then fed directly to a sensitive pen or light beam galvanometer recorder. More modern units contain Instrumentation Amplifiers to process the relatively low level signals coming from the various transducers.

Figure 2 is a line drawing of an Analog Instrumentation System which is capable of measuring wheel slip to develop Mu-Slip curves. Increased interest is being shown in this relationship as we get closer to the use of anti-skid braking systems on all highway vehicles.

The system has been shown in much the same manner as Figure 1, except that wheel speed tachometers have been added, plus a Slip Calculator, Mu Calculator, Mu-Slip Recorder and other associated equipment. The wheel speed generators are generally either DC tachometers or photo tachometers. Some trailers have used small 7, 9, or 11 segment tachometers, but unless properly mounted, they may be easily damaged. They have, however, been used on our own Skid Trailer for several thousand miles with no problems.

In looking at the Instrumentation Specifications you will recall that the Signal to Noise Ratio was specified as being 20 to 1. It is important to keep the noise level even lower, if possible, and to do so special attention must be directed to all wiring and disconnects. Waterproofing and prevention of corrosion are paramount. Location of components is critically important, and printed circuit board design must be done with an eye to preventing ground loops.

Due to the differences in tachometers and variation in the rolling radius between test tires, it is desirable to balance the slip output at the selected test speed. The null balance meter shown in Figure 2 allows this adjustment to be made.

An X-Y divider, generally of the four quadrant type, is used to calculate and determine Mu as a separate function. Such dividers can put out some pretty wild data if one of the inputs has a momentary input which is below zero. Considering the hysteresis allowed on load transducers, it is quite common to have a negative input during calibration, causing the operating technicians a great deal of trouble. One way to get away from this problem is to offset all zeros sufficiently in the positive direction to assure that permissible transducer tolerances will never completely override the offset. Such offsets must be taken into consideration in setting up the various recorder channels, but this is easily handled by an instrumentation engineer or technician.

Obviously, two recorders must be used to record the data since one group of data is on a Time Base and the other is on a Slip Base. At one time, not too long ago, X-Y Recorders were in use for recording Mu Slip data, but they were and still are too sluggish to produce good data. For this reason, Figure 2 shows the use of an Oscilloscope and Camera which is used to obtain the Mu Slip Curve.

The awkardness and time consumption of the photographic technique of recording Mu-Slip data led some skid trailer operators a few years ago to record the data on a multichannel FM tape recorder. The tape was later played back at a much lower speed to an X-Y Recorder which could then reproduce accurate curves.

Digital Instrumentation

In the past many trailers have used light beam oscillographs. Some of these units have as much as 2% nonlinearity. All of them use expensive paper. In addition, getting exact values from chart paper is sometimes very difficult. It is our experience that ±1.5 SN can be attributed just to the difficulty of analyzing the data. Therefore, our approach in the quest for improved accuracy and lower operating costs has been to utilize digital instrumentation, but the trend towards it has been very slow compared to the general use of computerization in other testing systems.

Figure 3 shows an instrumentation system similar to Figure 2, except that all parameters have been converted to a Digital format and recorded on a Digital tape recorder. The block diagram has omitted showing the signal conditioning, differential slip speed calculator, Mu calculator and the analog sequencer since they are not changed. The Speed Readout and SN Readout, generally DPM's, are also not shown since they remain the same.

Table 1. Basic Specifications Related to Instrumentation.

Items	SAE J345a	ASTM E274-70	ASTM F408-75
	Wet or Dry Pavement Passenger Car Tire Peak and Locked Wheel Braking Traction	Test for Skid Resistance of Paved Surfaces Using a Full Scale Tire	Standard Method of Testing Tires for Wet Traction--Using a Towed Trailer
Tire Load	100% T&RA @ 24 psi ±2.5	1085+0-200 pounds	
Inflation Pressure	24 psi cold ±½ psi		
Test Speed	20, 40, 60 ±1 mph	40 mph (64.4km/h)±.5 mph (0.8km/h)	20-60(32-96km/h)±.5mph(0.8km/h)
Speed Resolution or Accuracy	±.5%	±1.5% of Ind Spd or ±.5mph(0.8km/h)	±0.5 mph (0.8km/h)
Speed Slewing Rate			22% of full scale vlts/sec @22mph Max. full scale range 100 mph
Number of Locked Slides	10		
Slide Measurement Period	0.2-1.2 secs after Wheel Lockup		
SN Calculation	$F_H \div (W\text{-}h/L^F)$ for Torque Tube $F_H \div W$ for X-Y Transducer Type		
Standard Deviation Calculation	Use (n-1) as divisor		
NOTE: As applicable to both Peak and Slide			
Hitch Vertical Load	150 ±50 pounds	100 to 200 pounds	
Transducers	Design for Min. Inertial Effect		Minimize Inertial Effects
Transducer Hysteresis	±1%	Less than 2% of applied load	Less than 1%
Transducer Nonlinearity	±1%	Less than 2% of applied load	Less than 1% @ full scale
Transducer Cross Loading Effect	±1%	Less than 2% of applied load	Less than 2% @ full scale
Transducer Mounting	Less than 1% rotation for load range	Less than 1% rotation	Less than 1% rotation
Shunt Calibrating Resistors	Yes		
Cable & Strain Gage Waterproofing		Required	
Signal Conditioning			
Inertia Loading	Minimize effect. If not practical and effect exceeds 2% of actual data, correct for expected operation.	Minimal Effect	
Linear Output	Better than 2% data reading resolution		
Band Width	0-20 H_z (flat ±2%)		
Phase Relationship(All Signals)	0-20 H_z ±5 degrees		
Signal to Noise Ratio	20:1 desirable		
Recorder Frequency Response			D-C flat ±1% to 30 H_z full scale
Accuracy of Calibration System	Twice as accurate as other systems		
Brake Lockup Time	Not Specified	Less than 0.5 seconds	0.2 to 0.5 seconds
Center of Gravity		Less than 22" with 1085 Wheel Load	
Recorders		Not more than 1 sec for full scale deflection	
Recorders		Min. of 10mv full scale deflection	
Recorders		Must operate with min. of 500 ohm source impedance	

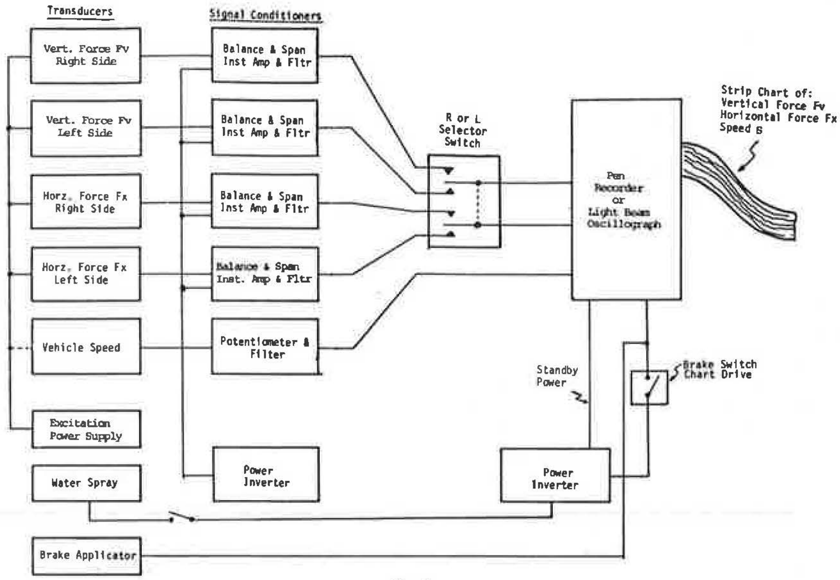

Transducers
Signal Conditioners
Vert. Force Fv Right Side
Vert. Force Fv Left Side
Horz. Force Fx Right Side
Horz. Force Fx Left Side
Vehicle Speed
Excitation Power Supply
Water Spray
Brake Applicator
Balance & Span Inst Amp & Fltr
Balance & Span Inst Amp & Fltr
Balance & Span Inst Amp & Fltr
Balance & Span Inst. Amp & Fltr
Potentiometer & Filter
Power Inverter
R or L Selector Switch
Pen Recorder or Light Beam Oscillograph
Strip Chart of: Vertical Force Fv Horizontal Force Fx Speed
Standby Power
Brake Switch Chart Drive
Power Inverter

Fig. 1

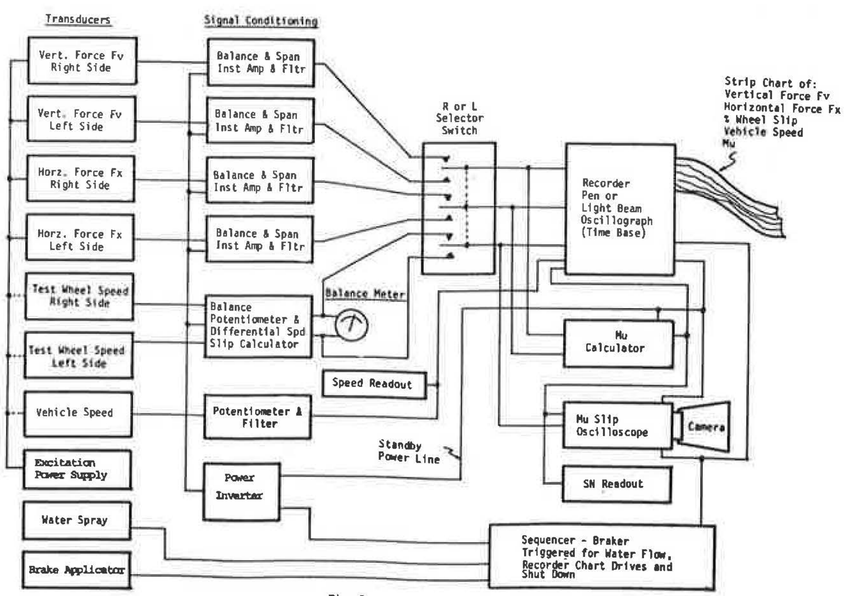

Transducers
Signal Conditioning
Vert. Force Fv Right Side
Vert. Force Fv Left Side
Horz. Force Fx Right Side
Horz. Force Fx Left Side
Test Wheel Speed Right Side
Test Wheel Speed Left Side
Vehicle Speed
Excitation Power Supply
Water Spray
Brake Applicator
Balance & Span Inst Amp & Fltr
Balance & Span Inst Amp & Fltr
Balance & Span Inst Amp & Fltr
Balance & Span Inst Amp & Fltr
Balance Potentiometer & Differential Spd Slip Calculator
Balance Meter
Speed Readout
Potentiometer & Filter
Power Inverter
R or L Selector Switch
Recorder Pen or Light Beam Oscillograph (Time Base)
Strip Chart of: Vertical Force Fv Horizontal Force Fx % Wheel Slip Vehicle Speed Mu
Mu Calculator
Mu Slip Oscilloscope
Camera
SN Readout
Standby Power Line
Sequencer - Braker Triggered for Water Flow, Recorder Chart Drives and Shut Down

Fig. 2

The system in Figure 3 makes possible fast acquisition of data in the field and allows for a slower playback during Mu-Slip plotting and extensive computer analysis to determine Peak and Slide values together with such information as Average Means, Standard Deviation, Variance and Standard Error of the Mean without the danger of transportation errors.

The CTI computerized data acquisition system is shown in Figure 4. The system consists of a programmable calculator as the main controller. Connected to the calculator's I/O port is an interface which consists of an analog multiplexer and an analog to digital converter. This unit allows the calculator to close the desired signal which will be converted to digital format. Inputs to the interface are taken directly from the instrumentation amplifiers or tachometer signal conditioning. No zero or span controls are required on any instrumentation amplifier.

The calculator has been programmed to compute input data during the lockup sequence. At the completion of the sequence, the calculator computes the Peak and Slide values during the skid. These values are printed on paper tape for presentation to the operator. The values are also stored automatically in memory for later calculation of the Mean, the Standard Deviation and the Standard Error of the Mean at the completion of a set of skids.

Calibration of the system is handled via calculation by entering values for zero offsets and gain factors. Auxiliary programs have been written to assist an operator in determining these values.

Computerized System Development

The computerized system methodology about to be described is the result of the authors' desire to:

1. Improve accuracy, repeatability and reliability of data.
2. Eliminate the use of extensive analog circuitry and calibration controls.
3. Eliminate the use of photo sensitive recording paper.
4. Allow data to be plotted in an easily readable and readily reproducible format.
5. Have an automatic alpha numerical printout of peak and slide SN's along with standard deviation and standard error of the mean prior to proceeding with the next series of skids.

Operation on the Skid Pad is quite simple. After attaining test speed, a START TEST command is given and the calculator controls the sampling of the required data and stores it into memory. The calculator then calculates and prints the Peak and Slide values for the operation. If it is desirable to plot the data, the calculation memory is recorded onto magnetic cards at the completion of each skid. At the completion of the 4 to 10 skids, the operator again depresses the proper keys on the keyboard and obtains a printout of Peak SN, Standard Deviation and Standard Error and Mean Slide SN with its Standard Deviation and Standard Error.

For the average determination of SN's for comparative purposes, the testing is complete at this point, since the statistical data has been printed out. However, for R & D work where it is desirable to show the Force, Speed and SN relationships Vs. Time, or Mu-Slip Curves, some additional steps are taken.

As was mentioned above, at the end of each skid the calculator memory is transferred onto magnetic cards. The magnetic cards are at a later time loaded into an identical calculator which has been interfaced to an X-Y Recorder in order to plot the data. (See Figure 5) Through simple commands an operator is able to plot Horizontal and Vertical Force, Vehicle Speed, Slip and SN Vs. Time. A Mu-Slip plot is also made so that the relationship between SN and Slip can be studied. An example of the plot is shown in Figure 6. As can be seen from the example, the data is easily readable and reproducible in a quick easy to use format.

Closing Comments

The use of a Computerized Instrumentation System has rewarded us by satisfying the early objectives we had. Ours is just one of many approaches that could have been taken and has provided us with very satisfactory results.

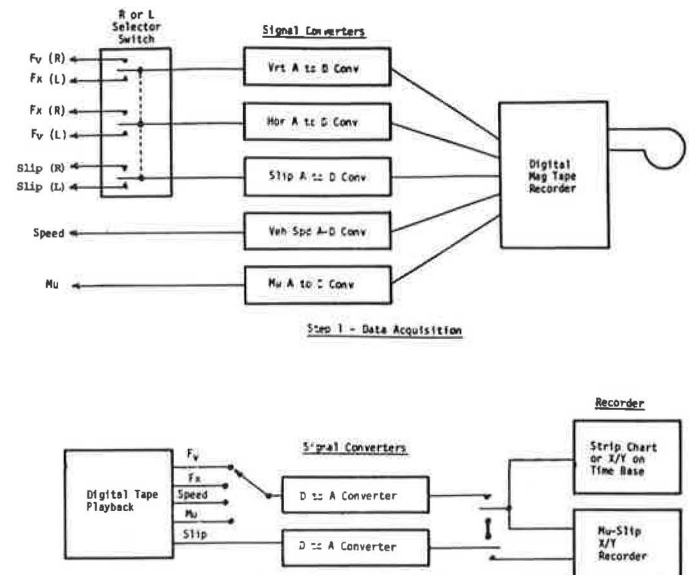
We have shown that the Computerized Methodology offers a significant improvement in reaching the goal of increased accuracy and reliability. Our system is in use today.

At the time of writing this paper, we must admit to being somewhat disturbed at seeing a move within both the ASTM and SAE to specify a Skid Trailer Accuracy Specification of ±3%. At a time when many are looking for ways to minimize as many differences between individual skid trailers as possible, it would appear that the opposite approach should be taken. In a general survey of the literature over the years, we have noted differences of 5 to 10 SN's between skid trailers. Of course, some of this can be attributed to test pad variations and to tire variations.

The fact that the basic transducers used appear to have shown no improvement for the last several years is bothersome. One would have expected the State of the Art over the last 10 to 15 years to have improved sufficiently to reduce the various transducer tolerances by 50%, to the order of ±1%, which is still ten times larger than is currently available in other types of force measuring transducers. Signal Conditioners and Analog Recorders are available today with an overall accuracy of less than ±0.5%. Digital processing offers even better accuracy. The trailer problem primarily appears to be the Vertical and Horizontal Force Transducers.

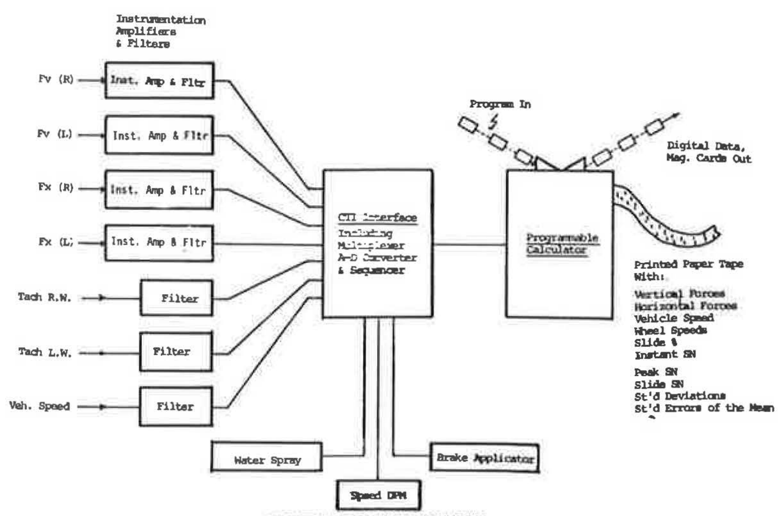
Another area needing close attention has to do with system frequency response. Most systems contain a filter, usually 20 or 30 Hertz; however, sufficient specifications for these filters have not been given. For instance, what type (Butterworth, Chevy Chev, etc.), how many poles (sharpness or roll off), band width flatness and phase response. We feel these requirements should be contained in the various specifications.

In our work with skid trailers we have concluded that Static Calibration on a platform is not too meaningful. We have seen evidence which leads us to believe that all transducers do not necessarily have the same output for a given dynamic horizontal force, although they do have an equal static output. No official work has ever been done on a study of this type to the best of our knowledge, but perhaps it is time for some responsive body to underwrite one. However, before this comparison work is made, using the same skid trailer, we would like to suggest that some attention be given to a Dynamic Calibration Platform, one which has imposed on its steady state pull a relatively low triangular impact wave shape to more closely simulate tests on road surfaces. Such a calibration platform would permit spans to be set in the



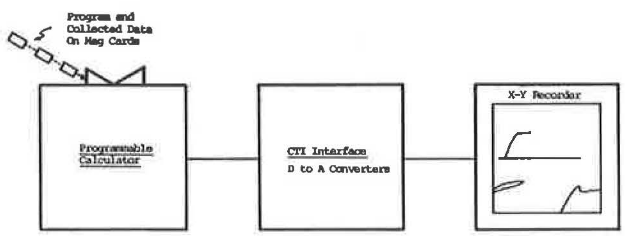
Step 2 - Data Recovery & Plotting

Fig. 3



COMPUTERIZED SYSTEM DATA ACQUISITION

Fig. 4



COMPUTERIZED DATA PLOTTING

Fig. 5

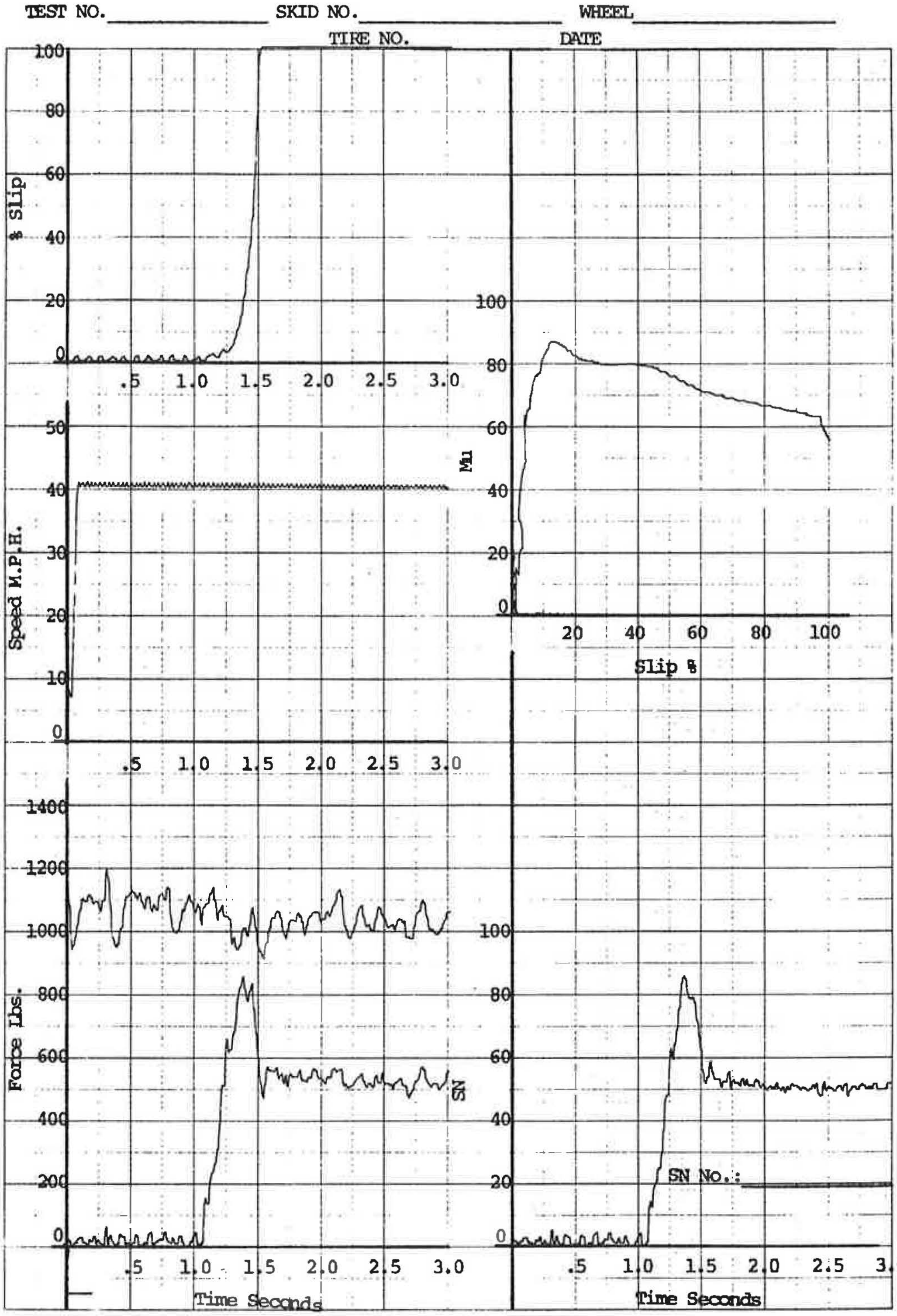

TEST NO.
SKID NO.
WHEEL
TIRE NO.
DATE
% Slip
Speed M.P.H.
Force lbs.
SN
Mu
Slip %
Time Seconds
Time Seconds
SN No.:

Fig. 6

field which we are sure would, in some instances, make corrections for certain transducers which apparently do not see a particular Static load in the same magnitude it would if the same load were presented to the transducer as an "average dynamic load."

References

1. Proceedings of First International Skid Prevention Conference, Part I.
2. National Cooperative Highway Research Program Report 151.
3. R. R. Hegmon, T. D. Gillespie, and W. E. Meyer. Measurement Principles Applied to Skid Testing. ASTM STP350, pp. 78-90.