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Band Friction Test Machine (SAE) Test Procedure

SAE Recommended Practice
Issued February 1987

Submitted for Recognition as an American National Standard

SAE The Engineering Society For Advancing Mobility Land Sea Air and Space
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HIGHWAY VEHICLE PRACTICE

Submitted for recognition as an American National Standard

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BAND FRICTION TEST MACHINE (SAE) TEST PROCEDURE

1. SCOPE: The SAE band friction test machine is used to evaluate the dynamic and static friction coefficients of automatic transmission band friction materials with automatic transmission fluids. It can also be used to conduct life tests on friction materials. This SAE Recommended Practice is intended as a guide toward implementation of a standard practice but may be subject to frequent change to keep pace with experience and technical advances. This should be kept in mind when considering its use.

2. TEST EQUIPMENT:

2.1 SAE band friction test stand with cycle timer and static breakaway accessory[1]

2.2 Flywheels to deliver desired kinetic energy

2.3 Recording oscillograph or equivalent system with at least four channels and a minimum system flat frequency response to record as follows:

2.3.1 Torque channel, 30 Hz

2.3.2 Pressure channel, 11 Hz

2.3.3 Speed channel, 11 Hz

2.3.4 Temperature channel, 11 Hz

[1]This machine is available from Greening Associates, Inc., Detroit, Michigan. Any other machine that is capable of reproducing the results of the Greening machine, as determined by the SAE Friction Subcommittee, would also be acceptable.

2.4 Torque transducer, full-bridge, strain gage type, combined nonlinearity and hysteresis effects not to exceed 0.5% full range

2.5 Apply pressure transducer, full-bridge, strain gage type, combined nonlinearity and hysteresis effects not to exceed 0.5% full range

2.6 Speed transducer, ±2% accuracy of full range

2.7 Test fluid temperature indicator, iron constantan thermocouple with high-impedance amplifier and cold-junction compensator; thermocouple located in test fluid

2.8 Jacket heater and/or cooler for test fluid temperature control

2.9 Adapters: Drum, apply strut and anchor

3. GENERAL OPERATING CONDITIONS AND TEST PARAMETERS:

3.1 Piston area 7 000 mm^2 to 14000 mm^2

3.2 Piston available travel 15.0 mm

3.3 Piston apply pressure - As required to produce desired unit loading, 35 to 520 kPa based on net area of friction material; tolerance on desired pressure to be ±7.0 kPa

3.4 Piston apply pressure rise rate 1000 to 1250 kPa/s

3.5 Piston release pressure, 40 kPa (to be 0 during apply cycle).

3.6 Total inertia range: 0.275 kg/m^2 (rotor only) to 0.616 kg/m^2 (with flywheels).

3.7 Dynamic engagement speeds 1750 or 3600 rpm

3.8 Kinetic energy 5 to 40 kJ

NOTE: In places where electric frequency is other than 60 Hz, an inverter may be used to obtain the recommended speed.

3.9 Average power per unit area:

$$W/mm^2 = \frac{KE\ (J)}{Area\ (mm^2) \times time\ (s)}$$

3.9.1 Friction evaluation (low energy) test, less than 1.2 W/mm^2 of net area

3.9.2 Wear life (high energy) abuse endurance test, more than 1.2 W/mm^2 of net area

3.10 Static breakaway speed, 1.75 rpm or variable

3.11 Test fluid quantity, 0.6 to 2.0 liter (see paragraph 4.8 below)

3.12 Test fluid temperature 110 to 120 C

3.13 Band average radial running clearance, 0.35 to 0.45 mm

3.14 Cycle time: dynamic 20 to 60 s, depending on inertia

3.14.1 Motor on time, 14 to 50 s

3.14.2 Piston apply time, 4 to 8 s

3.15 Cycle time, static breakaway 15 s

3.15.1 Motor on time, 1.0 s minimum

3.15.2 Pressure apply time, 2.0 s minimum

3.16 Oscillograph paper speeds

3.16.1 Dynamic tests, 50 mm/s minimum

3.16.2 Static tests, 25 mm/s

3.17 Oscillograph amplitude calibrations

3.17.1 Torque, 10.0 N·m/mm maximum

3.17.2 Pressure, 14 kPa/mm maximum

3.17.3 Speed, 80 rpm/mm maximum

3.18 Test duration, as required depending on test objectives as well as the cycles required to stabilize the frictional coefficient

NOTE: Typically 1000 to 2000 cycles are needed to stabilize the frictional coefficient.

3.19 Test cavity pressure, 15 kPa maximum

3.20 Cooling jacket pressure, 5 kPa maximum

4. TEST PREPARATION:

4.1 Clean and flush head of test fixture with test fluid. If the previous test was run with a fluid of different specification, clean the head with mineral spirits. Then flush once with new test fluid.

4.2 Immerse test bands in the test fluid for 15 s minimum at room temperature.

4.3 Measure and record the thickness of the friction material on each band 2.54 mm from both edges at six equally spaced locations beginning 2.54 mm from each end, before and after abuse endurance test. (Friction evaluation test should be run first.)

4.4 Mark on the drum face: The surface finish of the drum O.D. and the serial number of the band.

4.5 Install the band and drum, adjust the band to the specified torque on the drum, relax the band to the desired average radial running clearance.

4.6 Replace cover on test cavity.

4.7 Fill test cavity with specified amount of fluid, usually between 3 and 5 cm below the drum center. Vent the cavity while filling.

5. TESTING AND RECORDING:

5.1 Turn on power to recording equipment and warm up until stabilized.

5.2 Calibrate recording equipment to assure total torque and pressure system variance does not exceed 1% full scale.

5.3 Actuate temperature control system. This system may be manually or automatically controlled.

5.3.1 If the energy to be dissipated is sufficient to bring the temperature of the test fluid to the desired level in 10 cycles, no preheating should be necessary. Observe the temperature when the motor is running and the band is released.

5.3.2 Regardless of the heating or cooling medium used (oil, water, steam, or air), pressure within the jacket surrounding the test cavity should not exceed 5 kPa to prevent the cooling medium from entering the test cavity past the cover seal.

5.3.3 Heating or cooling of oil circulating through the test cavity is permitted but is not recommended, since purging and cleaning of the entire system after contamination is difficult.

5.4 Set the pressure level required for the test.

5.5 When the test temperature has stabilized, take oscillograph recordings as required. Record or mark the temperature on each record along with the cycle number.

NOTE: At this point, an aid, or reference, for evaluating the current oscillograph record is needed. One such aid is referred to as a master curve. A master curve can be developed from a series of tests by the method described below, in Section 6, Master Curve Calculations.

5.6 When obtaining data for a master curve, take five consecutive records after the minimum number of cycles required for break-in. Do this for each of six different samples, (bands).

5.7 Take a static record after each dynamic record, five total.

5.8 When a series of records is completed, mark the following information on the back of the last record:

5.8.1 Transmission model.

5.8.2 Type of band (intermediate, reverse, overdrive, etc.).

5.8.3 Friction material and manufacturer.

5.8.4 Oil-groove pattern plus pattern and number of oil relief holes.

5.8.5 Number of band wraps; i.e., single or double.

5.8.6 Previous testing or use history.

5.8.7 Test fluid specification.

5.8.8 Test fluid temperature.

5.8.9 Number of test.

5.8.10 Purpose of test.

5.8.11 Test date.

6. MASTER CURVE CALCULATIONS:

6.1 Dynamic Coefficient:

6.1.1 On the five consecutive records (traces) for each of the six samples, mark four speed points at 100, 500, 1000, and 2000 r/min. See Fig. 1.

6.1.2 Calculate the frictional coefficient at each speed, using one of the following relations:

Direction: Energized De-energized

$$\mu = \frac{1}{\theta} \ln \left[\frac{T + PAR}{PAR}\right] \qquad \mu = \frac{1}{\theta} \ln \left[\frac{PAR}{PAR - T}\right]$$

where: μ = coefficient of friction
T = value of torque from trace, N·m
A = area of apply piston, 0.007 m^2
R = radius of drum, (m), (varies for different bands)
P = applied pressure on piston, 35000 to 520000 Pa
θ = angle of band wrap, radians (double wrap band)

6.1.2 (Continued):

Sample computation: (Energized rotation direction)

$$\mu = \frac{1}{11.92} \ln \left[\frac{164.05 + (97000 \times 0.007 \times 0.0572)}{(97000 \times 0.007 \times 0.0572)} \right]$$

$$\mu = 0.139$$

6.1.3 Determine the average coefficient at each speed point for each of the six band samples using the following relation:

$$\mu_A = \frac{1}{n} \sum_{i=1}^{n} \mu_i$$

where: μ_A = average coefficient of one sample at one speed point
μ_i = coefficient from one torque reading at one speed point
n = number of torque readings at one speed point, five (5) taken from the five consecutive records (traces).

6.1.4 Determine if the six average coefficients, μ_A, at each speed point belong to a normal probability distribution as follows:

Arrange the six coefficients in order from lowest to highest. Plot these values on normal probability paper (for example: K&E 46 8003), according to L. G. Johnson's Median Rank Values[2] for a six-member sample, as given below:

Coefficient Rank	Median Rank, %
1 (lowest)	10.91
2	26.55
3	42.18
4	57.82
5	73.45
6 (highest)	89.09

6.1.5 If the plot (Fig. 2) on normal probability paper deviates markedly from a straight line, other than random errors are influencing the data. A check should be made for system errors.

[2]"Theory and Technique of Variation Research" by L. G. Johnson, Elsevier Publishing Company, New York, 1964.

6.1.6 Determine the standard deviations at each speed point as follows:

$$\sigma = \left[\frac{\sum_{i=1}^{n} \mu_{A_i}^2 - \frac{1}{n}\left(\sum_{i=1}^{n} \mu_{A_i}\right)^2}{n-1}\right]^{\frac{1}{2}}$$

where: σ = standard deviation
μ_{A_i} = individual average coefficient for each sample at the speed point
n = number of samples (six)

In practice, this computation is readily performed using an engineering calculator capable of statistical computations.

6.1.7 A band of acceptable values (upper and lower limits) for the dynamic friction coefficient is generated as follows: On linear graph paper plot friction coefficient versus sliding speed. See Fig. 3. The central line is the mean coefficient of all samples. The mean coefficient is defined as:

$$\bar{\mu}_A = \frac{1}{n}\sum_{i=1}^{n} \mu_{A_i}$$

where: $\bar{\mu}_A$ = mean coefficient of all samples at one speed point
$\bar{\mu}_{A_i}$ = average coefficient of one sample at one speed point
n = number of samples (six)

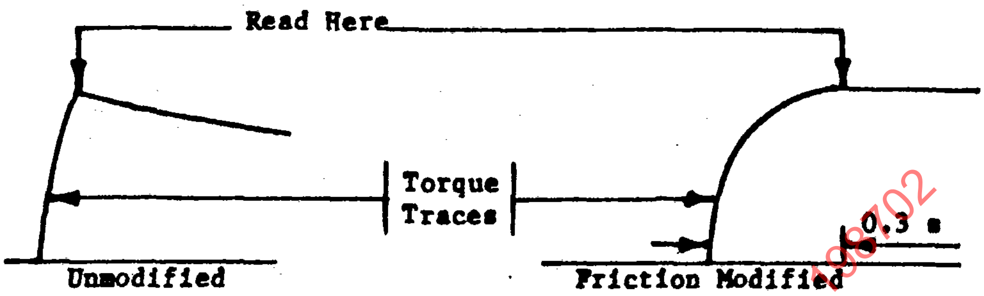
6.1.8 The upper and lower limit lines are generated from the average (central line by adding a constant times the estimated standard deviation for the upper line and subtracting for the lower. The constant is determined by the number of samples (n), the percentage of the population desired within the upper and lower end points (P) and the probability (confidence) that the estimates are correct. For: n=6, P=0.95 and C=0.90, use 3.723 as the constant.[3]

Upper Limit, $\bar{\mu}_A + 3.723\ \sigma$

Lower Limit, $\bar{\mu}_A - 3.723\ \sigma$

[3]Other constants may be used if different sample sizes and levels of risk are desired. See "Statistical Design and Analysis of Engineering Experiments" Lipson, Charles and Sheth, Narendra McGraw-Hill, pp. 80-81.

6.2 Static Coefficient, Master Bracket (Curve): The procedure is the same as in paragraph 6.1 except that there is only one speed point to consider, that is zero rpm. The advent of friction modified transmission fluids has made it necessary to read the torque trace recording in a different way.



Friction modified fluids cause the torque trace not to have a definite high point. Practice has shown that readings taken three tenths of a second (0.3 s) after the start of the torque rise, give more consistent results. Plot the static friction bracket values on the zero r/min line on the master curve.

7. DATA DISPLAY:

7.1 Master Overlay, Torque versus Time:

7.1.1 Another aid for evaluating the current oscillograph record is a clear plastic master overlay. In use, the overlay is placed on top of the record being evaluated, to see if the recorded torque trace is within the limits of the overlay.

7.1.2 The master overlay is developed from a minimum of thirty samples tested under identical conditions. When selecting traces for the superposition, discard those traces that would, on analysis, be outside the ±2 sigma limits for the current material combination.

7.1.3 The master overlay is generated as follows: Extend the zero torque line completely under the torque trace, in the direction of the time axis. Note, when the engagement is initiated the torque is already slightly above zero. This is due to band drag and viscous drag of the drum. Extend the torque rise back to the zero torque line. This intersection represents zero time, and it is the common point for superposition.

7.1.4 When all of the dynamic torque traces have been superimposed, trace an outline around the highest and lowest traces. See Fig. 4. This outline on a clear plastic sheet is the master overlay. See Fig. 5.

7.2 Data Sheet:

7.2.1 Record essential data on a sheet similar to Fig. 6.

BAND NUMBER	Friction Coefficient At Selected Sliding Speeds, r/min 100	500	1000	2000	STATIC	STOP TIME, s
1	0.142	0.132	0.128	0.102	0.137	0.96
2	0.142	0.135	0.129	0.102	0.129	0.96
3	0.148	0.132	0.130	0.102	0.132	0.94
4	0.150	0.136	0.133	0.099	0.145	0.92
5	0.148	0.133	0.130	0.097	0.137	0.95
6	0.144	0.130	0.127	0.102	0.127	0.94
$\sum_{i=1}^{6} \mu_{A_i}$	0.874	0.798	0.777	0.604	0.807	5.67
$\bar{\mu}_A$	0.1457	0.1330	0.1295	0.1007	0.1345	0.945
$\sum_{i=1}^{6} \mu_{A_i}^2$	0.127372	0.106158	0.100643	0.060826	0.108757	5.35930
$\frac{1}{6}\left(\sum_{i=1}^{6} \mu_{A_i}\right)^2$	0.127313	0.106134	0.100622	0.060803	0.108542	5.35815
σ	0.00344	0.00219	0.00207	0.00216	0.00657	0.01517
$\bar{\mu}_A + 3.723\,\sigma$	0.1585	0.1412	0.1372	0.1087	0.1590	1.001
$\bar{\mu}_A - 3.723\,\sigma$	0.1328	0.1248	0.1218	0.0927	0.1100	0.889

[a] Average of five recordings.
[b] The standard deviation, σ, is defined as follows:

$$\sigma = \left[\frac{\sum_{i=1}^{n} \mu_{A_i}^2 - \frac{1}{n}\left(\sum_{i=1}^{n} \mu_{A_i}\right)^2}{n-1} \right]^{\frac{1}{2}}$$

FIG. 1 - MASTER CURVE CALCULATIONS

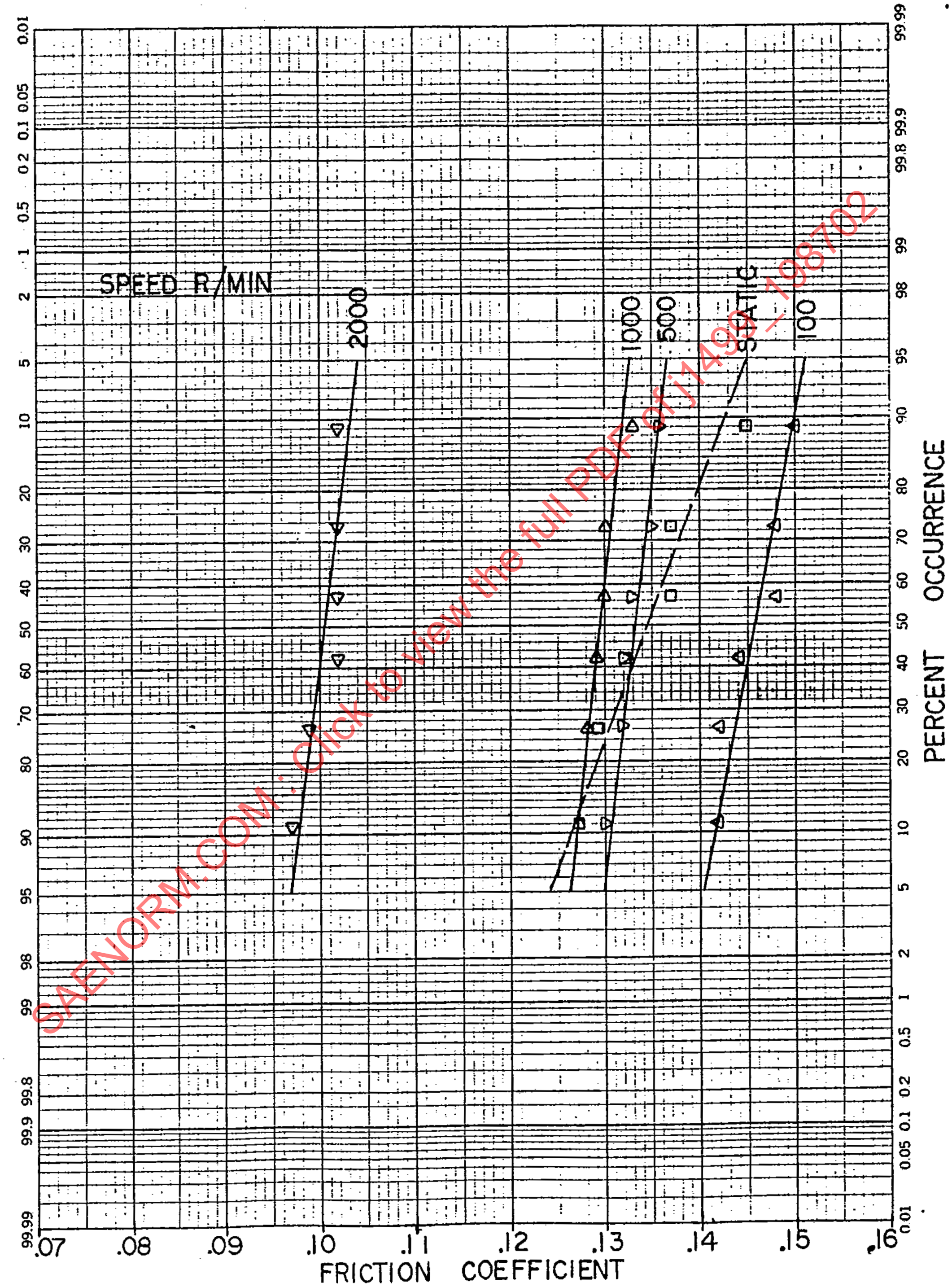


FIG. 2 - TEST FOR NORMAL PROBABILITY DISTRIBUTION

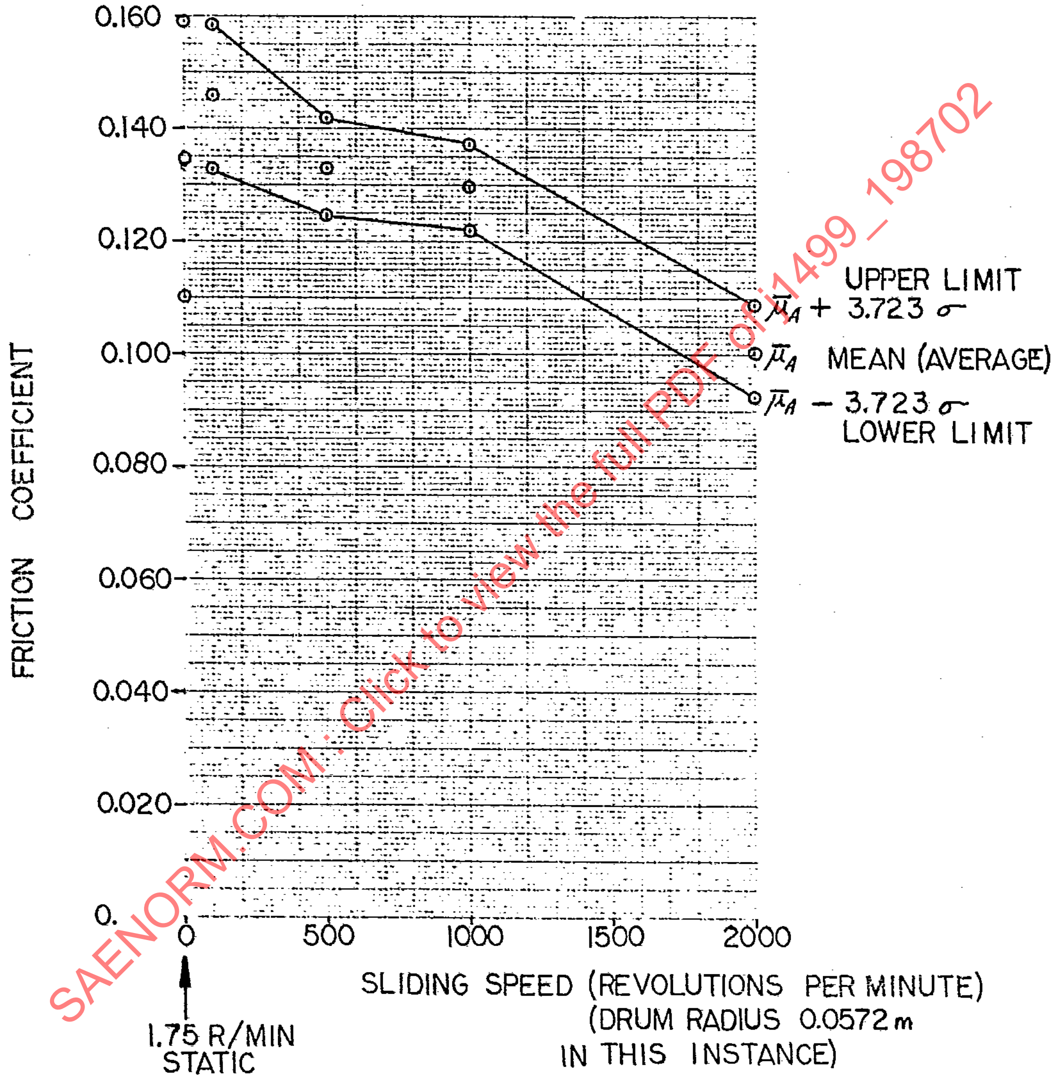


FIG. 3 - DYNAMIC FRICTION LIMITS

SCALE FACTORS
TORQUE 10.0 N·M / MM
TIME 0.01 S / MM

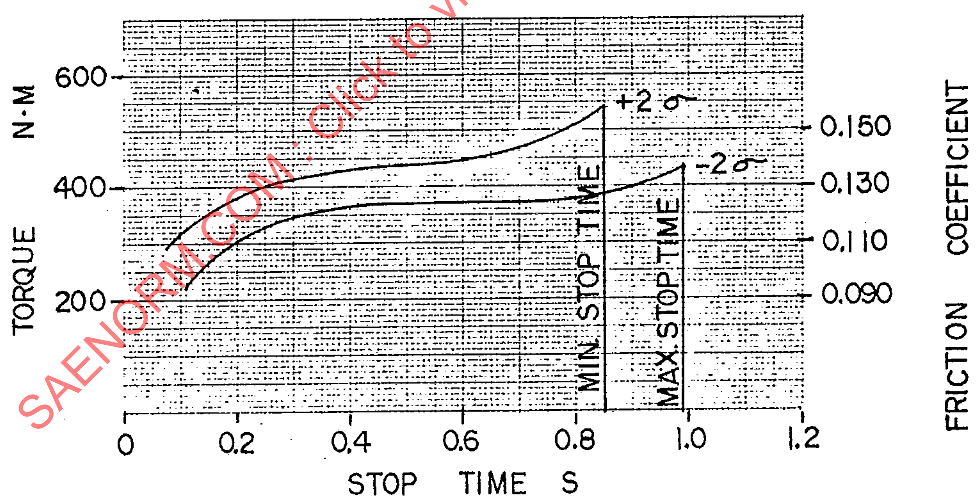


FIG. 4 - MASTER OVERLAY (TYPICAL)