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Preload and Drag Effects Due to Torque Applied to Spindle Nuts on Tractor-Trailer Wheel End Systems

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OBJECTIVE

This technical paper will identify the relationship of tapered roller bearing adjustment with respect to values of bearing preload force and rotational resistance caused by varying amounts of spindle nut installation torque.

An experimental process was developed using a test stand to which a conventional standard axle spindle was mounted. A commercial hub incorporating the tapered roller bearing components - described as cups, cones, a spindle nut and washer - completed the assembly selected for examination. The oil seal normally installed as part of the wheel-end system was not used in the interest of eliminating any rotational resistance (drag) associated with that component.

The testing apparatus included the means to measure the preload forces applied against the tapered roller bearings. This was done using a calibrated load cell and instrumentation to register pounds of force resulting from measured levels of torque applied to the spindle nut assembly. At each level of spindle nut adjustment, measurements of rotational resistance (drag) were recorded. The results showing the relative values of preload with respect to torque applied to the spindle nut were recorded

This static test involved a wheel bearing system without payload. For actual dynamic performance of a loaded system, it would be necessary to devise a dynamic testing capability using a special dynamometer.

With the data obtained, it was possible to develop graphic illustrations showing the relationship of preload force and the associated rotational resistance (drag) with respect to the amount of torque applied on the spindle nut. As the preload increased, greater levels of drag occurred. With the information obtained, variations of fuel expense resulting from drag were able to be determined.

In the interest of fuel conservation, it is anticipated that the results of this testing procedure will promote incentive to develop improved recommended practices for tapered roller bearing preload adjustment.

INTRODUCTION

“Controlled preload” for tapered roller bearing adjustment has not yet been accepted as an ideal procedure by many trucking industry professionals. Despite publication of recommended practices by the Technology & Maintenance Council (TMC) - as well as the Society of Automotive Engineers (SAE) *Surface Vehicle Recommended Practice, J2535*, general acceptance of a preload adjustment concept has not been realized.

One reason for the lack of progress has been reluctance on the part of wheel-end component manufacturers to issue instructions identifying how controlled preload can be installed. Some of this inaction can be attributed to the differing designs of the various nut systems. With fastener systems now available, a universal technique describing how preload should be installed requires further research and development.

Without a basic procedure, TMC has taken the position that if controlled preload is desired, the manufacturer of the wheel-end system must be consulted for appropriate instructions.

At this time, there are no installation procedures for controlled preload recommended by any spindle nut provider. Because of this impasse, Rather Engineering, P.C. became motivated to develop and examine a number of techniques for controlled preload with the belief that improved performance, greater reliability, and an added measure of safety will be offered in the future.

This paper deals specifically with accurately measured values of rolling resistance (drag) within a wheel-end assembled using spindle nut torque values in compliance with installation procedures currently stated in TMC *Recommended Practice, RP-618, Wheel Bearing Adjustment Procedure.*

HISTORY

Wheel separation accidents resulted in frequent fatalities and plagued the trucking industry in United States and Canada in the early 1990s. Investigations initiated by the National Transportation Safety Board (NTSB) provided statistical information relating to truck wheel separations. This information was published as a Special Investigation Report, NTSB/SIR-92-04, in September 1992.

Recommendations made by the NTSB as part of this report called for development and dissemination of model guidelines for the inspection and maintenance of all types of medium/heavy truck wheels. The NTSB also advocated development of uniform recommended practices to specify how often truck wheel bearings should be examined.

In response, a committee of engineers employed by tapered roller bearing manufacturers was formed by the SAE to produce the *Surface Vehicle Recommended Practice, J2535, Setting Preload in Heavy Duty Wheel Bearings*. This document defined certain design limitations, but nothing specific was provided to identify how much preload would be acceptable for heavy-duty vehicle operations.

SAE J2535 established that providers of axle components - not bearing manufacturers - should be responsible for issuing detailed instructions on how much preload force could be tolerated when using their products. At this time, recommendations do not identify maximum operating limitations for preload.

Further studies initiated by Rather Engineering, P.C. in 2007 confirmed that an essential element in wheel bearing adjustment had been largely ignored over the years. Drag, a principle factor in determining rolling resistance, was never described as being important. This is true because installation procedures known to reduce the amount of drag in conventional wheel-end assemblies did not exist.

Even today, in the absence of recommendations for wheel bearing preload adjustment, technicians are instructed to assemble wheels on axle spindles providing a measure of endplay to allow lateral movement of the hub on the axle. Rolling resistance remains relatively constant throughout the range of allowable endplay. Thus, drag does not increase until the spindle nut is tightened into the preload condition.

With testing, it has been confirmed that drag (rolling resistance) increases proportionately as the level of preload changes. However, further evaluations are needed to determine answers to the following questions:

1. How much preload force applied on the taper roller bearings can be tolerated before excessive expense results from added fuel consumption caused by increased levels of rolling resistance?

2. What amount of preload will result in a high level of operating temperature within the wheel-end assembly likely to cause oil seal and wheel bearing failures?

TEST METHODOLOGY

A test was developed by Rather Engineering, P.C. to obtain data to show how the value of installed preload imposed on the tapered roller bearings changes with respect to the amount of spindle nut torque applied during the installation procedure. The test setup incorporated the following components:

1. 1” diameter spindle with 1-14 UNF threads
2. 1-14 UNF conventional spindle nuts
3. hub having 6 studs on a 5.5” diameter
4. 1 ¼ ” and 1 ¾ ” ID tapered roller bearings
5. Sensotec Model GM display instrument (calibrated June 28, 2011)
6. Sensotec Model 13 load cell / 100 pound range (calibrated June 28, 2011)
7. 0 – 100 foot pound calibrated torque wrench
8. Adjustable protractor
9. Balance beam scale

After 200 foot pounds of torque were installed to set the bearing components and the oil seal, the spindle nut was backed-off to the just-loose condition. The second step in the process retightened the spindle nut with 45 foot pounds of initial adjustment torque while rotating the wheel. This reintroduced approximately 100 pounds of preload force within the assembly. The third step in the process was to back off the adjustment nut a second time. With this movement, the preload force applied against the tapered roller bearings was progressively reduced. This reversed rotation of the adjustment nut continued in the counter-clockwise direction until the preload force decreased to a minimal level.

This established the amount of spindle nut rotational back-off movement to reach the transition from preload to endplay. The amount of rotation was approximately 45 degrees. (This procedure replicates the protocol by which wheel bearings are adjusted in accordance with *the TMC Recommended Practice RP-618* in Figure 1.)

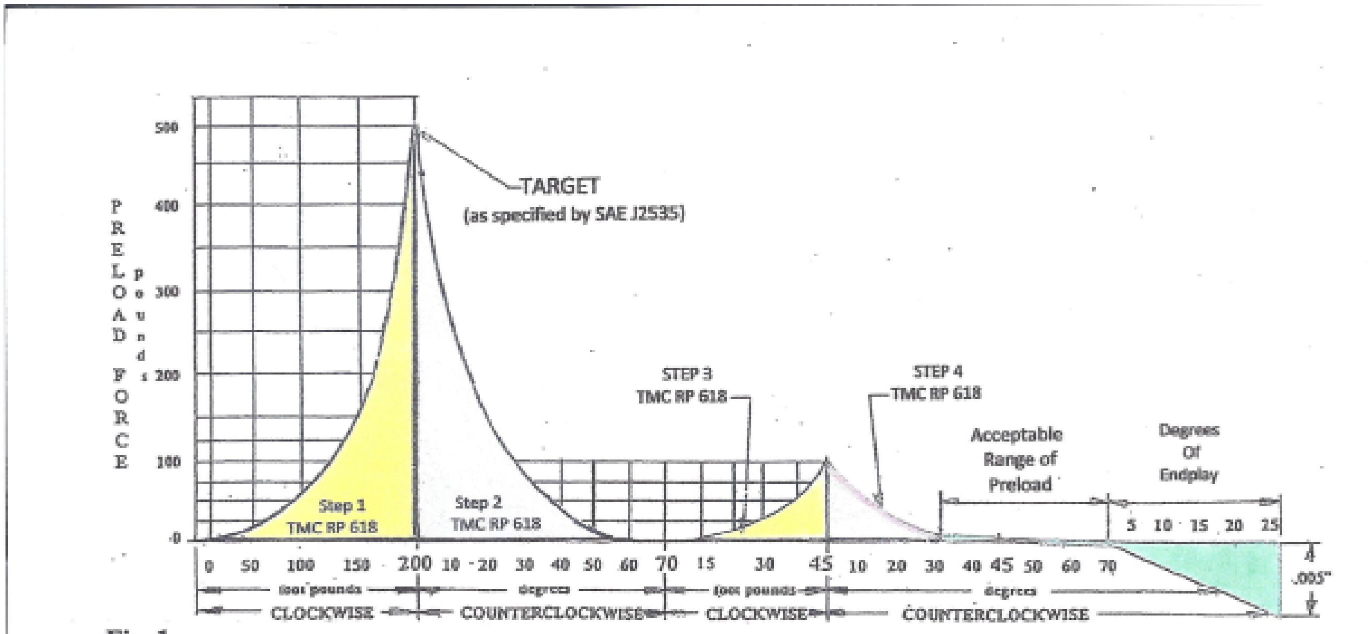

Fig. 1

DISCUSSION

The testing process described in the Test Methodology section established the procedure that enables an adjustable range of spindle nut torque to be identified. From the initial condition of 100 pounds of preload force, incremental reductions of preload force were made while applying a succession of five degree rotational reductions of the adjustment nut. The purpose of this process was to determine the amount of angular rotation of the spindle nut needed to reach the point where the preload force became totally relieved and the adjusted condition transitioned to endplay. The results of the testing procedure are illustrated in Figure 2. It must be recognized that differences in thread configuration affects the relationship of preload with respect to spindle nut torque. The results obtained from the examination of this one inch diameter (1-14 thread) axle spindle and nut combination will not apply to assemblies having different design characteristics. However, any axle/spindle nut configuration can be analyzed using this basic testing procedure to determine its unique preload/spindle nut torque relationship.

Manufacturers of spindle nuts are cautioned not to assume the specific values identified in Figure 2 will apply to their proprietary nut designs. The points of transition between preload and endplay will vary according to the differences in component design and must be evaluated independently.

With independent analyses by spindle nut manufacturers, it will be possible to identify the significant values of preload/torque with respect to each type of spindle nut. Recommended installation procedures covering each variation of spindle nut design can then be made.

RECENT FINDINGS

Recent performance testing on a one inch ID axle spindle discovered unexpected preload force variations that occur during a sequence of applied incremental levels of torque. This information provided a new understanding of a previously unrecognized preload/torque relationship. It was discovered that the level of preload diminishes gradually as torque is reduced in the adjustment process recommended in Step 4 of TMC *Recommended Practice RP-618.* In the case of a one-inch ID axle spindle with 1-14 USF threads, Figure 2 illustrates this unique relationship in the form of an exponential curve.

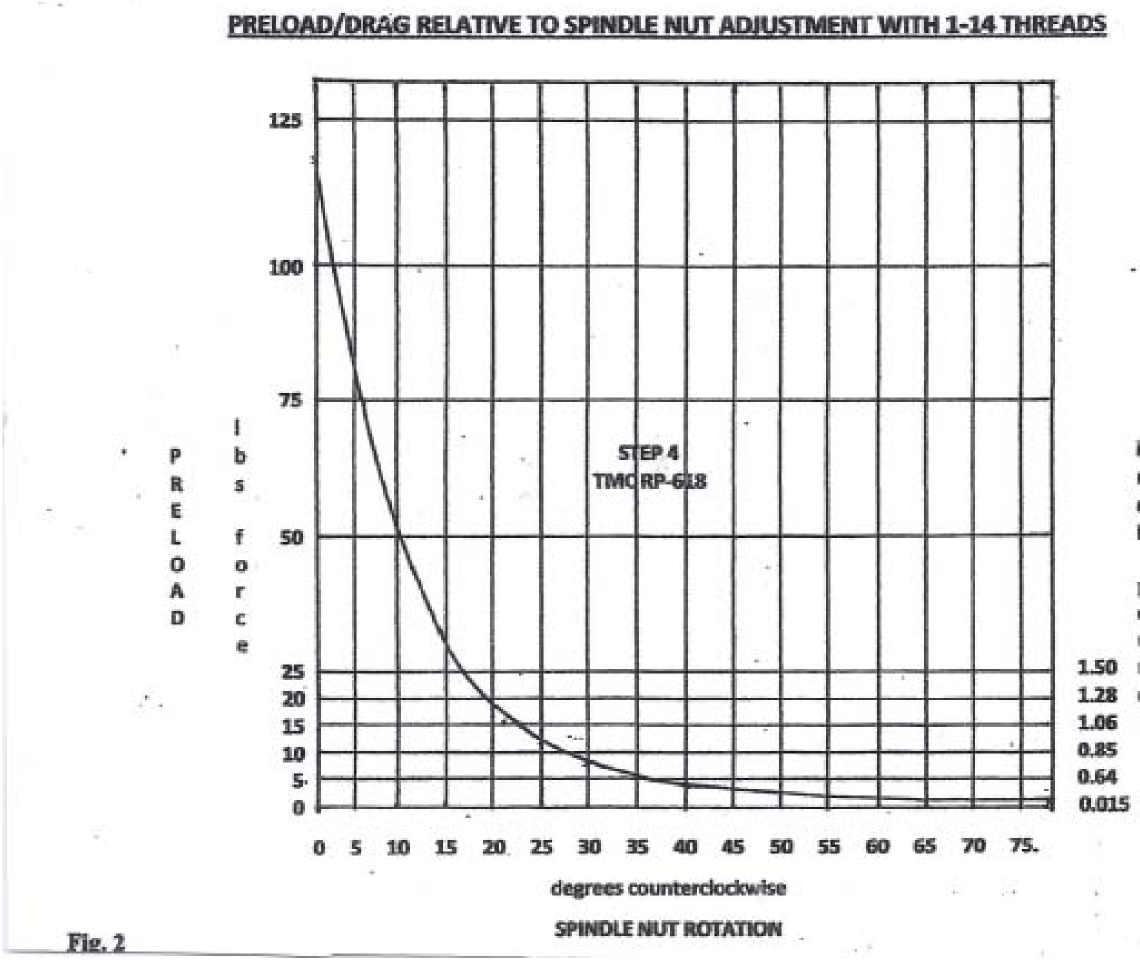

Fig. 2

The Technology & Maintenance Council *Recommended Practice RP-618* specifies a four-step procedure to reach a level of adjustment nut positioning from which final securement can be accomplished. Step 1 calls for an application of 200 foot pounds of torque to tighten the adjustment nut to seat the bearings and oil seal. Step 2 is a reduction of the initial torque to the level where looseness can be detected. Step 3 reapplies 50 foot pounds of torque to the spindle nut while rotating the hub to achieve the recommended condition from which Step 4 can be initiated. Step 4 is the process by which the spindle nut is loosened to reach the ideal adjustment where Drag and Preload forces are reduced to a minimum. These steps are illustrated in Figure l.

Figure 2 illustrates Step 4 shown in Figure 1 and it is most significant because it describes a characteristic of wheel bearing adjustment not previously recognized. Through the course of loosening the adjustment nut from approximately 115 pounds of preload force, the variation rate of preload relative to the number of degrees of nut loosening changes dramatically.

During the first 20 degrees of back-off rotation, the amount of preload force decreases rapidly. After reaching the 35 degree stage of adjustment nut back-off rotation, the curve levels out and diminishes gradually until the transition is reached where the condition of preload force changes to the condition of looseness associated with endplay.

Interestingly, an acceptable level of preload continues to be available until the 60 degree position of adjustment nut rotation is reached. This means than an additional 25 degrees of back-off spindle nut adjustment is available before endplay (looseness) occurs. This entire 25 degree range of adjustment provides “a light preload bearing setting” of less than 5 pounds of preload force.

It will be relatively simple for all spindle nut manufacturers to capitalize on this new knowledge to provide fastener systems able to be secured within this desirable 25 degree range. Total compliance with the recommendations of both *SAE RP J2535* and *TMC RP-618* is now possible assuring “a light preload bearing setting” that is consistently repeatable.

DRAG

The amount of spindle nut torque not only determines how much endplay or preload results from adjustment of the tapered roller bearings, but it also causes variations of drag - a factor associated with rolling resistance. It is known that if the spindle nut is tightened excessively, high levels of drag may cause severe consequences.

Manufacturers of tapered roller bearings have cautioned that bearings will not perform safely if they are adjusted with excessive spindle nut installation torque. The manufacturers further advise that if the intention is to eliminate endplay, the amount of preload must be controlled. However, little has been said about the adverse consequences that may happen if too much drag is introduced within the wheel-end system.

On occasion, the amount of heat generated by over-tightened spindle nuts may cause deterioration of the roller bearings leading to wheel separation accidents. Also, there have been reported instances of lubricant fires in wheel-end assemblies due to becoming excessively heated.

A tapered roller bearing wheel end system affected by too much preload produces heat in a manner similar to that of the brake system. The energy involved is converted to heat which is dissipated by conventional means of cooling. If the means for cooling are insufficient, higher temperatures will cause wheel bearing failure and oil seal deterioration.

These problems are directly associated with excessive drag. Unfortunately, the trucking industry has not been adequately informed that increased drag (rolling resistance) will occur whenever wheel bearing preload levels are elevated. By minimizing the amount of applied preload, lower operating temperatures of the tapered roller bearings will result and reduced fuel consumption will be assured.

DRAG TESTING PROCEDURES

This technical paper suggests how wheel end component manufacturers can determine how their products might be adjusted to achieve economical levels of controlled preload. During the test procedures, precise measurements were made of forces needed to cause the wheel hub to rotate. Accurate measurements of the amount of torque needed to initiate hub rotation at the instant rolling resistance (drag) was overcome were recorded. Drag is a variable that can be controlled by adjusting the amount of torque applied to the adjustment nut. The value of drag (inch pounds) is a function by which the radius (inches) at which the measured force applied is multiplied by the amount of force (pounds) measured at that radius. The measured data collected during the testing procedure is documented in the Appendix for reference to be used to develop Figure 2.

CONCLUSIONS

Despite the testing accomplished in the preparation of this technical paper, the findings are not conclusive enough to adequately answer the two questions earlier identified in the History section. Reflecting on the first question, excessive drag will cause additional fuel expense, but the static test procedures used showing increased drag in this instance are not applicable to loaded axles in dynamic operations on the highway. Expanded testing procedures will be needed to investigate all varieties of wheel end systems in the interest of examining the overall effect of drag associated with heavy-duty vehicles involved in highway operations. More comprehensive testing facilities will be needed.

Regarding the second question - what amount of preload will result in a high level of operating temperature within the wheel-end assembly likely to cause oil seal and wheel bearing failures – it will not be possible to establish the specific level of preload associated with dangerously high wheel bearing temperatures until new testing techniques become available to examine all of the dynamic variables involved. A special dynamometer to enable examination of wheel-end systems under loaded conditions at specified rates of speed needs to be developed.

The testing performed in preparation for this technical paper definitely shows that a relationship exists between levels of preload and the amounts of drag within a tapered roller bearing system due to torque applied to the spindle nut. It was also shown that various levels of applied spindle nut torque can be correlated with measured amounts of preload and drag.

SUMMARY

This testing activity by Rather Engineering, P.C. was prompted in the interest of learning more about tapered roller bearing wheel-end adjustment because of industry advisories stating preload would be acceptable as long as it was “controlled

SUMMARY (cont’d)

In the course of this testing activity, it was recognized that a gradual diminishment of applied preload force occurs as the spindle nut is loosened from its initial fit- up tightness of 50 foot pounds of torque. This new insight of gradual diminishment confirms there is a significant range of preload force that makes it possible to safely select various degrees of adjustment.

With this broad range of adjustment, it will become possible for manufacturers of wheel-end systems to provide recommended practices to explain how their products can be installed to achieve controlled preload in compliance with specific recommendations published by the TMC. Currently, an SAE committee is also considering how the *Recommended Practice J2535, Setting Preload in Heavy-Duty Wheel Bearings*, should be restated to eliminate some perceived deficiencies. Efforts have also been advanced to clarify some of the definitions appearing in the original document.

RECOMMENDATIONS

Future testing methods involving preload should consider the means for axle systems to be studied using dynamometers capable of analyzing factors of speed and load as well as the variable characteristics of wheel-end fastening systems.

Of particular importance is the need for greater insight with respect to the effects of rolling resistance (drag) caused by excessive amounts of preload force. It is not presently known how significant rolling resistance due to preload is in the determination of fuel consumption economics. However, annual fuel expense will increase to some degree if excessive preload comes into play.

Tapered roller bearing manufacturers have accumulated information and data pertaining to controlled preload that could be of interest to component manufacturers within the industry. Concerted effort by all manufacturers involved should be made to encourage availability of this important engineering information.

In the future, spindle nut manufacturers should be the most logical providers of appropriate future recommended practices to assure ideal ranges of preload on tapered roller bearings for heavy-duty vehicle operations.

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A P PE N D I X

POUNDS OF PRELOAD APPLIED BY DEGREES OF ROTATION

Test #1, July 28, 2011

Clockwise

DEGREES	Position 1	Position 2	Position 3	Position 4	Position5	Position 6	AVERAGE
5	0.40	0.52	0.59	0.53	0.49	0.58	0.53
10	074	0.50	0.46	0.61	0.72	0.61	0.61
15	0.61	0.71	0.63	0.71	0.71	0.37	0.67
20	1.77	-.96	2.30	1.40	1.05	1.62	1.47
25	2.93	2.70	3.04	2.18	5.70	2.87	2.89
30	3.63	3.59	6.44	4.38	6.02	2.25	4.16
35	10.75	6.02	11.69	13.70	14.20	13.47	12.40
40	13.32	13.00	21.05	28.50	18.78	12.99	18.40
45	30.00	30.85	29.43	26.60	30.93	32.46	30.30
50	57.42	59.18	60.63	54.01	49..40	48.12	55.00
55	82.89	74.71	80.14	78.50	72.09	74.48	76.96
60	108.60	114.78	112.37	115.24	101.12	115.12	112.72

Counterclockwise

0	115.43	119.02	122.20	114.44	105.25	118.47	116.84
5	85.45	73.50	101.90	85.27	83.60	83.60	84.48
10	72.76	72.13	72.35	66.62	63.01	67.81	70.13
15	37.85	25.35	33.30	34.51	30.20	32.54	32.64
20	15.75	17.20	18.36	20.78	16.20	14.94	16.88
25	11.97	13.64	13.60	15.50	10.96	12.87	12.54
30	8.93	6.94	9.51	10.23	11.02	5.57	8.90
35	5.67	2.73	3.73	7.80	5.31	2.10	4.23
40	1.77	0.96	2.30	1.40	1.05	1.62	1.47
45	0.61	0.71	0.63	0.71	0.71	0.37	0.67

The first group of 12 sets of values presented above lists the averaged readings of six measurements registered for each set made as the spindle nut was tightened at five degree increments. The first three readings register values within the zone of endplay and the fourth established the transition point at which the first preload value of 1.47 pounds force was registered. After tightening the spindle nut with 45 foot pounds of torque, 112.72 pounds of preload force was registered on the load cell display instrument.

With incremental back off at five degree increments, it was determined that 40 degrees of counterclockwise movement of the spindle nut was needed to reach the original preload transition level of 1.47 pounds force.

Figure 2 was developed using the preload force values recorded above.

Test #3   August 4, 2011

This test to enable drag calculations considered averaged amounts of preload force applied at six levels of torque reduced incrementally from an initial application of 45 root pounds of spindle nut torque.

POUNDS OF PRELOAD APPLIED

Preload Setting	Case #1	Case #2	Case #3	Case #4	Case #5	Case #6	Case #7
1	100.79	78.27	63.75	27.44	30.16	2.64	0.81
2	92.29	81.18	58.92	23.30	9.71	5.77	0.17
3	105.56	91.68	56.60	20.16	13.90	2.13	0.56
4	94.16	91.68	56.60	38.26	8.53	10.11	0.20
5	91.50	89.12	53.16	23.83	23.71	3.38	0.05
6	96.53	81.12	51.09	21.52	16.16	1.76	0.04
AVERAGE	94.94	82.96	56.37	22.20	13.87	3.75	0.52

APPLIED WEIGHT TO OVERCOME DRAG AT THE ABOVE AVERAGE PRELOAD SETTINGS

	Case #1	Case #2	Case #3	Case #4	Case #5	Case #6	Case #7
Grams	808.8	473.5	392.8	188.9	143.0	75.2	33.0
Pounds	3.78	1.04	0.87	0.42	0.32	0.27	0.07

CALCULATIONS TO DETERMINE THE AMOUNT OF DRAG AT EACH OF THE PRELOAD SETTINGS

CIRCUMFERENCE OF THE DRAG WHEEL = 21.95 inches

RADIUS = 21.95 / 2 π = 3.49 INCHES

DRAG EQUALS POUNDS FORCE TIMES THE RADIUS OF THE DRAG WHEEL

	Case #1	Case #2	Case #3	Case #4	Case #5	Case #6	Case #7
Drag in inch pounds	6.21	3.63	3.03	1.47	1.12	0.58	0.25

Data from Test #3 shows the averaged readings for applied preload at seven incremental positions to better examine the characteristics of the curve shown in Figure 2. This was in the interest of providing a closer examination of the measured values for both drag and preload forces with respect to the degree of spindle nut back off from the 25 foot pound preload force level.

Four preload settings identified as Cases 4, 5, 6, and 7 provided specific plots for the curve represented in Figure 2 from the 25 pound force level to the 1 pound force level which correlates with drag values from 1.47 inch pounds to 0.25 inch pounds of drag. This represents the range of the curve generated after the original 100.79 pounds force of preload was reduced to approximately 25 pounds force after 15 degrees of spindle nut back off.

It is significant that the amount of drag increases exponentially during clockwise rotation of the spindle nut after the condition of adjustment changes from endplay to preload. This suggests that adjustment procedures would be better controlled if final settings were reached by counterclockwise adjustment nut rotation after establishing a specific level of tightness.