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Effect of Capper Head Rotation Speed
On Immediate Removal Torque

presented by

Xiaole Fan

has been accepted towards fulfillment
of the requirements for

Master degree in Packaging

Hugh E. Lockhart
Major professor

Date June 23, 1999

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EFFECT OF CAPPER HEAD ROTATION SPEED ON IMMEDIATE REMOVAL TORQUE

By

Xiaole Fan

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

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ABSTRACT

EFFECT OF CAPPER HEAD ROTATION SPEED ON IMMEDIATE REMOVAL TORQUE

By

Xiaole Fan

The rotary capper is one of the two most popular kinds of capping machines being used in today's packaging line. A research project was designed to investigate the relationship between the chuck rotation speed and immediate removal torque of three plastic bottle and cap systems.

Polypropylene caps (28-400) were applied to high density polyethylene bottles at nine rotation speeds and three application torque levels. Three liner systems were used (F-217, P/SF and P/RVTLF). Immediate removal torque (IRT) increased with rotation speed for all three liners. However, the pulp systems leveled off at 450 - 500 rpm, while the F-217 liner continued to increase sharply through that range. All changes were non-linear.

The F-217 (polyethylene) liner is a viscoelastic material, while the pulp liners are not. Consequently, the effect of rotational speed (inertia) increase remained constant for F-217 over a range of four application torques, while for pulp liner, it decreased. The pulp liners crush, the F-217 does not.

To Mom And Dad,

My Husband,

For Love And Everything You Have Done For Me.

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LIST OF SYMBOLS AND ABBREVIATIONS

ANOVA	=	Analysis of Variance
ASTM	=	American Society of Testing and Materials
AT	=	Application Torque
Ave.	=	Average
HDPE	=	High Density Polyethylene
IRT	=	Immediate Removal Torque
PE	=	Polyethylene
PP	=	Polypropylene
SP	=	Start Position
ST	=	Static Torque
Std. Dev.	=	Standard Deviation
TIP	=	Torque Inch Pounds*
USP	=	United State Pharmacopoeia

*This term is widely used by closure and bottle manufacturers. It is also referred to as Inch Pounds Of Torque.

INTRODUCTION

Capping is a critical task in the packaging process. Applying the correct type of closure to a particular type of container at the right speed is vital to both a packager's integrity and a packager's reputation. All the consumer knows about closures is that they should be easy to open and close. According to "Consumers Rate Packaging Traits -- A Packaging Digest Exclusive Survey" (Packaging Digest, July 1995), these two traits rank as some of the most important characteristics of a packager, whether for foods, pharmaceuticals or personal care products.

One the other hand, speed is essential in today's packaging industry. In order to increase output, more and more high speed filling-capping lines have been introduced to the packaging industry. How to ensure the capping quality while speeding up the whole production line has become a major issue in quality control and packaging.

Many researches have been conducted by either machinery manufacturers or machinery users in areas such as how to speed up the cap feeding speed or increase the head number in order to meet the speed of the entire filling-capping line. However, very few studies investigate the detail of the actual capping process and related torque behavior.

A research study was developed at Michigan State University with industry representatives from packaging machinery manufacturers, bottle and closure manufacturers, pharmaceutical companies, food companies, and consumer product companies. The study focused on how to control the capping speed in order to get proper closure tightness. The goal of this study was to explore the relationship between immediate removal torque and application speed based on a series of well-designed laboratory experiments. Also, the study was designed to look at the effect of liner materials at different capping speeds.

The liner materials chosen are commonly used liner systems in the packaging industry. Non child resistant polypropylene caps (28-400) were applied to high density polyethylene square bottles at nine rotation speeds and three application torque levels. Three liner systems, F-217, P/SF and P/RVTLF, were used.

The F-217 (polyethylene) liner is a polyethylene foam material, while P/SF and P/RVTLF are the pulp back materials with different surface coating systems. F-217 is highly viscoelastic, while P/SF and P/RVTLF are not. So the different torque behavior and capping speed effect based on these two different lining systems were expected.

The rotary capper used in this study was donated by Fowler Co. It was a German made semi-automatic capping machine with an adjustable magnetic chuck. The static torque can be easily set by changing the distance between the inner and outer magnets in the chuck. The spindle speed was also adjustable by turning the handwheel on the back of the motor. The experiments were designed based on these machine characteristics.

LITERATURE REVIEW

1. Rotary Cappers

Rotary cappers are widely used in today's packaging lines. Many researches have been conducted by machinery manufacturers in areas such as how to speed up the cap feeding or increase the head number in order to meet the speed of the entire filling-capping line. However very few publications mention the detail of actual capping process and related torque behavior.

Anon (1990) stated:" Cappers vary widely in complexity, and this complexity is directly related to the speed of the capping process." He also reported that at the low end of the scale, a single-spindle capper runs at speeds to 60 containers per minute. Speeds range from about 120 to 220 per minute for the four-head unit, 180 to 330 a minute for the six-head unit and 300 per minute and higher for the eight-head machine.

Anon (1987, 1990) described the rotary capper mechanism in detail. Typically, the capping operation begins as the cap buttons pick up a cap and transfers it to the chuck. This transfer takes place so that the cap coincides with and comes down upon the top of the container. With a rotary capping system, the chuck follows the container around. The chuck then opens and lifts away. The container (with its cap in place) moves on, to be discharged from the machine. On a single-spindle machine, the cap is picked up as described, but the bottle is held in position.

In the case of conventional cappers, a structure is usually adopted that exerts static load on a torque plate by spring force or air pressure, and torque is transmitted by torque clutch to a cap held in the chuck, which is descending to apply the cap. At this time, the container is fixed by a gripper and the container may not be turned during cap closing. When the closing torque reaches a certain value, the torque plate starts to slip so that any more torque is not transmitted between cap and container. The quantity of this closing torque is adjustable to increase or decrease the load against the torque plate. For instance, torque quantity is decided by strength of the spring constant of the spring in case of spring loading and by quantity of pressure in case of pneumatic loading.

Serchuk, A. (1979) described two kinds of chuck: mechanically and air driven. The most important benefit of air drive is the ability to adjust torque while the capper is operating. Torque limiting on any capper may be through the use of a slip-clutch arrangement that overrides at a preset torque limit. Another arrangement depends on balancing pressure in a pair of air cylinders. Air driven cappers usually also use air to operate the chuck jaws that grip the cap--jaws are lined with a variety of materials to grip the cap without marring it. Air drive may be the most practical where explosion-proof equipment is a must although the air driven equipment can be complex and costly on multiple head, high-speed gear.

The other way to drive a chuck-type capper is mechanically. Instead of air motors, these are powered through gears, rods, and cams coupled to an electric motor. Their chucks, however, use a variety of means to grip the cap. Simplest may be the use of a coil spring that slides over the cap and holds it during transfer. The actual torquing is done by a plate in the chuck pressing down as the chuck spins. This method works best with a flat cap. Other chuck designs use jaws to grasp and torque the caps. Where some chuck designs depend on friction between the chuck and cap to apply torque, these also grasp. Whichever method may be used, the shape of the chuck surfaces and the choice of facing materials may be made to accommodate the particular cap. And this is a major feature of the chuck capper. Serchuck, A. (1979) described the experiences about this feature with Laub Engineering Company. The fact is that only chucks can torque specialty caps -- an extreme example would be the designs frequently used on nail polish. Otherwise, they would have to be applied by hand and tightened by machine, which makes little sense where large production quantities are involved.

There is another type of chuck that has been brought into our sights recently. It is the magnetic chuck. It has been widely used by Fowler Co. in their products -- the rotary cappers for many years. As a matter of fact, this kind of chuck has been used for this project.

Figure 1 shows a magnetic chuck with a gripping jaw. Figure 2 shows four components of a magnetic chuck head: chuck housing, outer magnetic ring, spring used on the upper part of the jaw and a gripping jaw. Figure 3 and 4 are the top and front views of two magnets -- an outer magnetic ring and a inner magnetic ring with a chuck housing.

Figure 1 Magnetic Chuck Connected with Capping Jaw

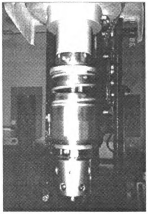


Figure 2 Four Components of the Magnetic Chuck

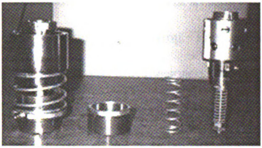


Figure 3 Top View of the Magnetic Rings
(Left is the inner ring with housing; right is the outer ring.)

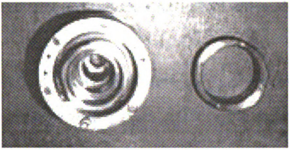
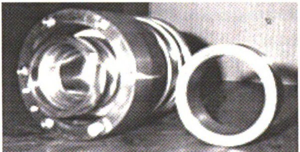


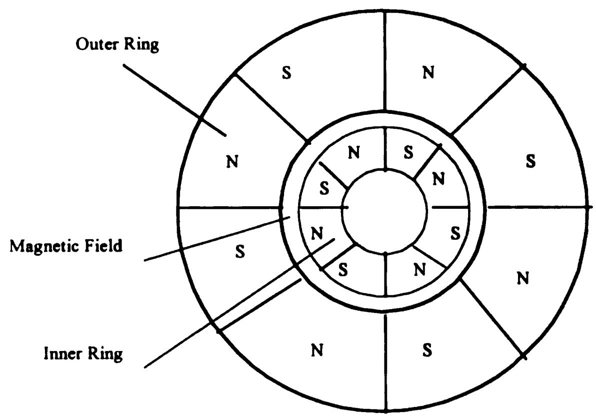
Figure 4 Front View of the Magnetic Rings
(Left is the inner ring with housing; right is the outer ring.)



The inside of the outer magnetic ring is magnetic as well as the outside of the inner ring. Both rings have continuous threads on them so they can be easily assembled by screwing the outer ring onto the inner magnetic ring. The outer magnetic ring also has threads on its outside in order to be screwed into the space between the chuck housing and inner magnetic ring. The depth of the engagement determines the intensity of the magnetic field and it can be easily adjusted by screwing the outer magnetic ring more or less deeply into the housing. In Figure 3 and 4, there is a big bolt on the top of the housing. This bolt acts as a "stopper". Once it's been loosened, the outer magnetic ring is movable. After the adjustment being made, the bolt needs to be tightened to fix the position of the outer magnetic ring so that the magnetic field will produce a fixed force for a specific torque value.

There are several ways to magnetize the outer and inner metal rings. One is to embed several magnets into the metal ring. Another is to partially magnetize the metal ring with heat treatment. By whichever method they were magnetized, the results are the same. There is a north pole and a south pole located adjacently in the metal ring. See Figure 5. The north pole on the outer ring and south pole on the inner ring attracts each other. When the outer ring is rotated with the chuck housing, the stable position of two magnets (outer and inner) is destroyed. The magnetic poles on each ring will exert magnetic force to overcome the resistance and get themselves back into the stable position. This force will work on the capping jaw as a rotational torque and the torque will be transmitted to the cap by the jaw. The torque varies with the intensity of the magnetic field, which can be controlled by the degree of the thread engagement on both outer and inner magnetic rings.

Figure 5 Magnetic Poles on the Outer and Inner Magnetic Ring



About the cap feeding system, Anon (1990) introduced three methods. The main method is the contour approach, whereby the cap is caught by its open end using a contour-and-pin system. The machine picks up a cap from a jumbled supply in a hopper so that the machine can orient it. Cap feeding is also done using a vibratory system. This equipment vibrates a flow of caps toward the capper and works to discharge or remove any that are not properly oriented. A third method uses a centrifugal hopper with a rotating disc. This system fits properly oriented caps into a chute which feeds them to the capping chuck.

Anon (1990) also stated that "the need for versatility is another major consideration when choosing a capping machine. Packagers must decide between a single-purpose unit or one with more adaptability. One compromise is a capper with a wide enough dimensional range to accommodated larger caps that may be used in future packaging."

A servo system is a useful tool to increase the versatility of a capper. Noone, William J. (1995), senior editor of Packaging Technology & Engineering, wrote about servo technology in torquing system. The use of servo torquing has enabled users to achieve fast and efficient changeover. Servo torquing allows cap tightening control to be done via a servo drive, permitting push-button torque adjustment. Caps and liners can be selected from a pre-programmed menu, and torques for different cap sizes and styles can be selected in seconds.

2. Torque Behavior

Greenway, G. W.; Danville, D. R. and Lazzara, F. L. (1973) did a definitive study that identified factors influencing removal-torque decay for PP and PS closure on HDPE bottles. As a part of the study, they evaluated both speed and dwell time of cap application. The rotation speeds chosen were 48, 72, 115, 151 and 193 rpm. They found that "with constant application torque, increases in both cap-application speed and dwell time also increase removal torque. But such removal-torque increases level off at higher speeds and dwell times." Also they found when application torque and capping speed are held constant, an increase in cap-application dwell time results in an increase in removal torque.

Serchuk, A. (1979) pointed out that material was the unknown element in the capping operation. Between the side-wheel and the chuck cappers it would seem the machine designers have everything under control. And, if all things were equal, that might be the case. However, all things are seldom equal, and in this case the troublesome element is the bottle or jar. The fact of the matter is that the container manufacturing processes just aren't sufficiently controllable to guarantee trouble-free capping operations. Packers complain of containers that lean to such a degree they don't align properly in chucks. Serchuk went on to say that others refer to flash in the finish area of plastic containers that interferes with torquing. Even though suppliers produce containers in accordance with a common specification, there are variations from supplier to supplier that could require some adjustment to the capper. Serchuk said that neck supports for the bottle are the most common solution for this alignment problem.

He also stated that as a matter of practice, the creation of torque depends on a number of factors, but most important are the materials involved-- the cap, the container, and the liner if used. Other factors coming into play include temperature, time, and a variety of other stresses. Among the other realities of torque application, according to Serchuk:

- Caps on hot-filled containers may require little removal torque at room temperature, unless there's a vacuum seal.
- Plastic caps tend to loosen and back off with time because of plastic's elastic memory.
- It may be impossible to predict removal torque of a cap because of the temperature variations and vibrations sustained during shipment and storage of the container.

Anon (1990) also talked about several factors that affect the final removal torque. One aspect of maintaining correct torque is the impact the labeling machine has on the capped container farther down the packaging line. In establishing torque standards for a particular cap/container system, it is essential to check the effect of the pressure on the cap by the labeler. This pressure may dictate a change in the torque which, in turn, affects adjustment and operation of the capper. When capping a hot-filled product, for example, problems can result when the product cools. The cap will "back off"-- that is, loosen itself or reduce removal torque. To overcome this, some packagers employ a secondary tightening operation (called retorquing) after the cooling process.

For the closure "back-off" problem, Serchuk, A. (1979) reported that it could be reduced to some extent by redesigning the finish thread to have more of a flat under surface--the so-called M-style thread.

3. Torque Control

Anon (1987) introduced a new torque control system. Cappers developed in Japan offer a more accurate closing method than conventional cappers where screw caps are found to be either too loose or too tight. The microprocessor-controlled system based on a torque measuring system reproduces the hand-capping process and enables the control of the opening torque by controlling the closing torque. Two types of capper, the single head rotary type and multi-head rotary type are described and compared with conventional capper operation.

The biggest problem in the capping process is the variation of the immediate removal torque. Sometimes the range of variation is so big that the cap could be totally loose or too tight to open. Different types of capper have different reasons for this. For the conventional mechanical rotary capper, Anon (1987) stated that the coefficient of friction of the torque plate plays a major role in causing the torque to vary beyond its tolerance. The temperature of the torque plate rises during the course of continuous operation, so the static friction coefficient and dynamic friction coefficient of the torque plate are gradually varying. The torque value, which can be transmitted by torque clutch, is closely related to these friction coefficients and the maximum transmissible torque is naturally changing with the rising of torque plate temperature. For this reason, in case of spring torque, the spring needs to be changed to conform to the change of coefficient of friction. For the pneumatic torque system, the air pressure needs to be adjusted with change of friction coefficient. For a turret rotary capper (a capper with multiple capping heads), each head has to be adjusted for the spring or the air pressure. The adjustment needs to be balanced within the multiple heads in order to achieve the same application torque. The truth is that in reality it is impossible to make these adjustments during the actual production.

So, in order to solve the problem without unrealistically making any changes during the production , a new torque control system was developed based on a measuring system operated by a microcomputer. A load cell, which actually is a torque sensor, is connected with the gripper shaft by a connection rod. The application torque is transmitted as a force to the load cell by the gripper and the connection rod. After measuring the actual application torque, the load cell will send a signal, which is the measurement, to the microcomputer. The computer will compare the incoming signal to a preset target application torque and then give the feedback signal to two air valves, which are used to control the inside air pressure of the torque chamber. The air pressure of the torque plate will be adjusted according to the feedback signal so that a target torque can be achieved.

For the single head rotary capper, which is an intermittent type capper, it is necessary to complete cap supply, cap closing and torque control during standstill of the machine, because the operation is carried on within a cycle of container movement --

stop, then move for a pitch. For the multi-head rotary capper, the cap supply, cap closing and torque control needs to be completed between the way-in star wheel and the way-out star wheel.

4. Viscoelasticity

Viscoelasticity, as its name implies, is the incorporation of viscous effects into elasticity. The ideal linear elastic element is the spring. When a tensile force is applied to it, the increase in distance between its two ends is proportional to the force. The ideal linear viscous element is the dashpot. It has the property that, when a tensile force is applied to it, the sides of the piston move apart at a rate that is proportional to the force. A loose fitting piston in a liquid-filled cylinder, arranged so that liquid flows out around the sides of the piston when it moves slowly up the cylinder, is an example of such an element.

The general development and broad application of the linear theory of viscoelasticity occurred during the 1970s. According to Christensen, R. M. (1971), the activity in this field has been primarily due to the large-scale development and utilization of polymeric materials. Many of these developed materials exhibit mechanical response characteristics which are outside the scope of such theories of mechanical behavior as elasticity and viscosity. The theory of elasticity may account for materials that have a capacity to store mechanical energy with no dissipation of the energy. On the other hand, a Newtonian viscous fluid in a nonhydrostatic stress state implies a capacity for dissipating energy, but none for storing it. Materials that are outside the scope of these two theories are those for which some, but not all, of the work done to deform them, can be recovered. Such materials possess a capacity to both store and dissipate mechanical energy.

Christensen, R. M. (1971) stated that a different way of characterizing these materials was through the nature of their response to a suddenly applied uniform force on a specimen. An elastic material, when subjected to a suddenly applied loading state held constant thereafter, responds instantaneously with a state of deformation which remains constant. A Newtonian viscous fluid responds by a steady flow process. There are, however, materials for which a suddenly applied force induces an instantaneous deformation followed by a flow process which may or may not be limited in magnitude as time grows. A material which responds in this manner is said to exhibit both an instantaneous elasticity and creep characteristics. This behavior is clearly not described by either an elasticity or a viscosity theory but combines features of each.

It is instructive to consider a situation which represents a generalization of the response to a single suddenly applied force. Suppose a material having the instantaneous elasticity and creep characteristics described above is subjected to two nonsimultaneously applied sudden forces, superimposed upon each other. After the first application of force, but before the second, the material responds in some time dependent manner which depends upon the magnitude of the first force. But now consider the situation that exists at an arbitrarily small interval of time after the sudden application of the second force. The material not only experiences the instantaneous response but also a continuing time dependent response due to the first applied force. An elastic material would respond only to the total force at every instant of time. Thus, this more general type of material possesses a characteristic which can be descriptively referred to as a memory effect. That is, the material response is not only determined by current conditions, but is also determined by all past states of force. A similar situation exists if one considers the deformation as being specified, and thus, the current force depends upon the entire past history of deformation.

This "memory" is different from the one in plasticity theory (Christensen, R. M., 1971). Plasticity is independent of the time scale involved in loading and unloading programs while the viscoelastic effects have a specific time or rate dependence. Generally speaking, for the viscoelastic material, the faster the loading, the higher the force.

The two liner materials used for this project are polyethylene foam and pulp. Polyethylene is a highly viscoelastic material. It responds to the speed of loading. As a liner material in the application of torque, the faster the compression force it receives, the higher its resistance to deformation. On the other hand, pulp is not a viscoelastic material. Instead, it has some elasticity and does respond to the change of loading, but the effect of loading speed is very limited. The bottle used in this project was high-density polyethylene and the closure was polypropylene. Both of them are characterized by plasticity, which contains some degree of elasticity.

MATERIALS, EQUIPMENT & METHODS

A. Materials

- Upjohn 28-400 60ml high density polyethylene square bottle
- Owens-Illinois 28-400 non child-resistant polypropylene closure(white) with polyethylene foam F-217 liner. The F-217 liner is 0.040" O-B Seal I - A three-ply coextrusion material. Foamed low density polyethylene core between two layers of low density polyethylene.
- Owens-Illinois 28-400 non child-resistant polypropylene closure (white) with P/SF pulp back liner. The liner is 0.035" P/SF - 0.035" pulpboard adhesive bonded to 0.004" white sulfite paper to which is adhesive laminated a 0.00075" saran film.
- Owens-Illinois 28-400 non child-resistant polypropylene closure (black) with P/RVTLF pulp back liner. The liner is 0.035" P/RVTLF - 0.035" pulpboard adhesive bonded to 0.003" bleached Kraft paper extrusion coated with 0.001" high density polyethylene which is coated with a 0.004" white, thermosetting, vinyl chloride acetate coating to which is applied a lubricant finish wax treatment (0.2 to 0.8 mgs./sq. in.).

B. Equipment

- Zalkin TM3 Semi-automatic Rotary Capping Machine - Type N^{o} 32820, with magnetic clutch, manufactured by Fowler Products Company. See Figure 6 and 7. For more detailed introduction of this machine, please see Appendix A, which is the operating manual provided by the manufacturer, the Fowler Co.

Figure 6 Front View of Zalkin TM3 Semi-automatic Rotary Capping Machine

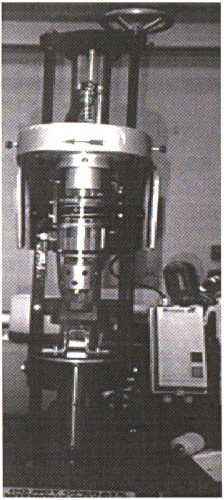
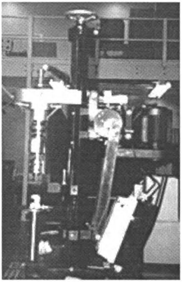


Figure 7 Side View of Zalkin TM3 Semi-automatic Rotary Capping Machine



- Pocket-Tach 20, Model 98-900-4 non-contact tachometer, Swiss Precision Instruments, Inc.
- Secure Pack Torque Tester Electronic Model (Digital Display), Serial # 25 461CD3

C. Method

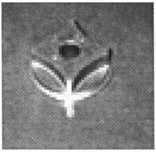
Data presented in Method 1 and 4 are not the test results. They are parts of the test method.

1. Static Torque Study

Static torque is a head or torsionnal force as measured when stationary only by hand. The magnetic chuck needs to be set for this torque in order to produce an application torque when performing the capping operation. A setting gauge was provided by the machine manufacturer for movement reference. See Figure 8. There are four reference marks on it (Mark 12, Mark 17, Mark 22 and Mark 27).

The four numbers (12, 17, 22 and 27) are actually marked, one number on each of the four flats. These flats are different thickness for spacing the magnets. The four marks are fixed points on the gauge. The clutch could also be set for spacings between the fixed points. For this project, the fixed points were used along with one intermediate point to set the application torques.

Figure 8 Setting Gauge for Static Torque



In order to find the relationship between the marks and actual static torques, a small study was conducted, which was to set measured static torque for each mark and measure the torque on the torque meter. For detailed procedure of setting a static torque using the reference gauge, please refer to Appendix A.

After setting the static torque, the torque was measured 10 times. The results show that position marks on the setting gauge do not represent the real torque value. They are just index marks. Table 1 shows the measured static torques of each testing level.

Table 1 Reference Marks and Corresponding Static Torques

No.	**Mark 12**	**Mark 17**	**Mark in between 12 - 17**	**Mark 27**
	Static Torque (TIP)	Static Torque (TIP)	Static Torque (TIP)	Static Torque (TIP)
1	8.9	13.9	11.6	24.7
2	8.9	13.8	11.7	24.7
3	9.0	13.9	12.0	24.5
4	8.9	13.9	11.9	2.4.6
5	8.8	13.8	11.6	24.5
6	8.9	13.9	11.6	24.5
7	9.1	13.8	11.7	24.6
8	8.8	14.0	11.5	24.6
9	9.1	14.0	11.5	24.8
10	8.9	13.8	11.6	24.8
Average	**8.93**	**13.88**	**11.67**	**24.63**
Std. Dev.	0.10	0.08	0.16	0.12

2. Testing for Chuck Rotation Speed Effect

Set a certain static torque and chuck rotation speed, apply the closure to the bottle. Under each static torque and rotation speed, three liner systems were tested. Sample size was 30 for each combination. Nine rotation speeds and three static torque levels were tested. See Table 2, which shows the machine settings for the speed effect test.

The static torques for this testing were set based on the USP recommended application torque value. According to USP <661> Containers / Physical Tests, the suggested tightness range with application torque for closure diameter 28 mm is 12 - 21 TIP. Because the actual application torque increases with the capping speed, the three static torques chosen for this project were 8.9 TIP (Mark 12), 11.7 TIP and 14.0 TIP (Mark 17) so that the application torque would fall into the recommended range.

For detailed procedure, please refer to Appendix A.

Table 2 Combinations of Machine Settings and Liners Tested in Rotation Speed Experiment

Static Torque / Speed of Rotation	8.9 TIP (Mark 12)*	11.7 TIP	14.0 TIP (Mark 17)*	24.6 TIP (Mark 27)*
120 rpm	F-217, P/SF, P/RVTLF	F-217, P/SF, P/RVTLF	F-217, P/SF, P/RVTLF	F-217, P/SF
150 rpm	F-217, P/SF, P/RVTLF	F-217, P/SF, P/RVTLF	F-217, P/SF, P/RVTLF	---
200 rpm	F-217, P/SF, P/RVTLF	F-217, P/SF, P/RVTLF	F-217, P/SF, P/RVTLF	---
250 rpm	F-217, P/SF, P/RVTLF	F-217, P/SF, P/RVTLF	F-217, P/SF, P/RVTLF	---
300 rpm	F-217, P/SF, P/RVTLF	F-217, P/SF, P/RVTLF	F-217, P/SF, P/RVTLF	---
350 rpm	F-217, P/SF, P/RVTLF	F-217, P/SF, P/RVTLF	F-217, P/SF, P/RVTLF	---
400 rpm	F-217, P/SF, P/RVTLF	F-217, P/SF, P/RVTLF	F-217, P/SF, P/RVTLF	---
450 rpm	F-217, P/SF, P/RVTLF	F-217, P/SF, P/RVTLF	F-217, P/SF, P/RVTLF	---
490 rpm	F-217, P/SF, P/RVTLF	F-217, P/SF, P/RVTLF	F-217, P/SF, P/RVTLF	F-217, P/SF

3. High Static Torque Test for Comparison of Polyethylene Foam Liner and Pulp Liner

Set static torque at 25 TIP (Mark 27) and rotation speed at 120 rpm and 490 rpm. Only the white closure with P/SF pulp and F-217 liner systems was tested. The black closure with P/RVTLF liner system was not tested because the black coloring pigment may also be a factor that affects the testing results in addition to the liner material (Greenway, Gerald, Raviwongse, R., and Samaranayake, V., 1994). See Table 2 for testing condition and machine setting.

4. Testing for Effect of Marking Closure Thread Start Position

The capper used in this research controls the application torque by the magnetic chuck. The magnetic chuck releases at a target torque. Descent of head and torque control are independent of each other and head descent is not controllable independently of speed.

The match of the closure thread and bottle thread is crucial for proper tightness. If the closure thread start happens to match the bottle thread start, the torque application happens right at the first revolution and the system will have enough dwell time for the capping chuck to make multiple impacts on the closure-bottle system. Then the application torque gets very high so that sometimes it is even greater than it should be and the cap will be very tight. Under this circumstance, the value of immediate removal torque reaches the upper limit or the maximum value. On the other hand, if the closure thread start doesn't match the bottle start in the first place, it will take several revolutions for the thread system to engage, then apply the torque. At that time the chuck is ready to release the closure, so the cap is either not tight enough or totally loose, so that the value of immediate removal torque is only 1 or 2 TIP, sometimes even zero. During the testing of 1 sample (30 bottles), this situation can happen up to 10 times or only 0 to 1 times depending on the random match of threads. So the alignment of the closure thread start and bottle thread start is uncontrollable and the number of impacts is incidental. There is a simultaneous interaction between head decent and number of impacts.

To try to solve the loose cap problem, the cap thread start position was marked and the cap was put into the chuck at certain position by reference to the marked start position. But the test results were still not satisfactory. Sometimes there was no difference from the data of start position not marked. Because of the way the machine works, there is no way to ultimately control the match of the threads.

In order to see the effect of marking the closure thread start position, two series of tests were run for all three lining materials: start position marked and start position not marked. Static torque 14 TIP (Mark 17) was the machine setting. At certain rotation speeds, there was a difference of immediate removal torque but this was not true at all speeds. However, generally the marked caps showed slightly greater mean IRT values. The statistical analysis showed the same results. So marking start position does not make better and more accurate data. Figures 8, 9, & 10 show the IRT value from testing of SP marked and SP not marked.

Figure 9 IRT for SP Marked and SP not Marked for F-217 Liner under ST 14.0 TIP

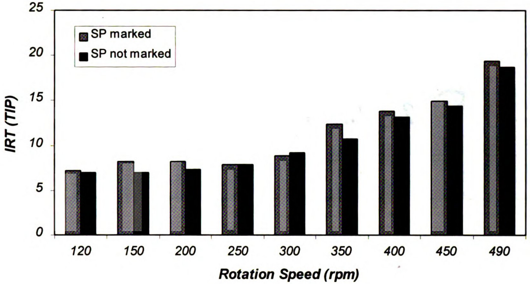


Figure 10 IRT for SP Marked and SP not Marked for P/SF Liner under ST 14.0 TIP

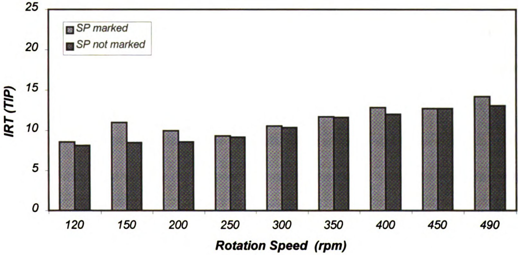
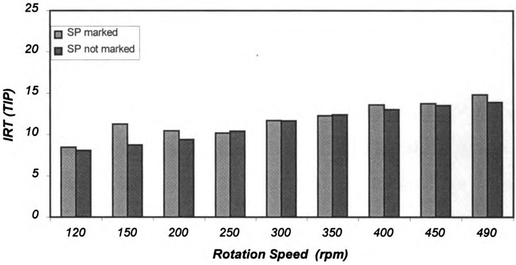


Figure 11 IRT for SP Marked and SP not Marked for P/RVTLF Liner under ST 14.0 TIP



There is another reason why marking start position was not used for the research. Statistically, if we want to make a comparison between samples, the samples have to come from the same population. Under the situation of closure thread start position not marked, sampling is random. 1 sample (30 bottles) consists of all kinds of closure-bottle threads match. Some of them match right after the closure touches the bottle, some of them take several revolutions to engage, some of them could match during the last revolution and do not have time to be torqued. Data of each speed level are from the same population and we can do the comparison among those speed levels. Under the circumstance of closure thread start position marked, it is another story. Even though the closure thread start position was marked and the closure was put into the chuck at certain place, the match point would be uncertain and would change from one operation to another operation. For example, at speed level 150 rpm the threads might engage after 1 revolution and at 250 rpm the engagement could happen after 3 revolution. Different thread match points result in different application torques and ultimately different immediate removal torque. Data for 150 rpm and data for 250 rpm are from different populations. Therefore data from start position marked can not be used to compare with each other for the purpose of seeing the speed effects.

Because of the above, the test protocol was not to mark thread start. Unreasonably low immediate removal torque readings (IRT < 3 TIP) were ignored and replacement specimens were prepared. All valid data in this thesis are from the testing of closure with start position not marked. The data validation will be justified in "Results and Discussion" chapter, on page 42.

5. Impact Test:

    Since the match of threads can not be controlled, some of the closure-bottle systems undergo more impacts from the chuck because their threads match at the very beginning of the revolution and have more dwell time. Therefore, some of the systems undergo proper number of chuck impacts and some of them do not even have one impact.

    In order to see if the number of chuck impacts makes any difference in application torque or immediate removal torque, an impact test was performed.

    Set static torque at 9 TIP (Mark 12), apply the closure to the bottle by manually turning the bottle one impact. Sample size was 30. Then under same static torque, use the same closure-bottle system, apply the cap by manually turning the bottle eight impacts. Only the white closure with F-217 liner and P/SF pulp liner systems were tested. The black closure with P/RVTLF liner system was not tested because the black color pigment of the closure may also be a factor that will affect the test results. Caps applied at static torque level 14 TIP (Mark 17) were also tested.

6. Statistical Analysis for the Experimental Data

Minitab Version 11.2 was used to implement all statistical analyses including analyses of variance (ANOVA). For two-sample comparisons, the pooled approach to estimation of standard deviation was used.

An ANOVA was run for each liner material under each static torque in order to see the speed effects over the whole range of chuck rotation speed. ANOVA was also run to see the statistical significance in impact test and analysis of marking thread start position.

RESULTS AND DISCUSSION

Speed Effect

Over the speed range of 120 rpm to 490 rpm, the immediate removal torque increases as the chuck rotation speed goes up. This is true for all three lining materials. See Figures 12 - 17. Figures 12 - 14 show the speed effects at each static torque level for all three tested liner systems. Figures 15 - 17 show the speed effects of each liner material for all three static torque levels. The increase is non-linear in all cases.

As a result of the speed effect, the machine can be set in several different ways to get a target immediate removal torque. For example, in Figure 15, immediate removal torque 9 TIP can be obtained by setting the machine in 3 ways: static torque 8.9 TIP, rotation speed 350 rpm; static torque 11.5 TIP, rotation speed 320 rpm or static torque 14.0 TIP, rotation speed 300 rpm. The same use can be made of all of Figures 12 - 17.

The curve of F-217 has a much bigger slope than the curves of the two pulp liners do. Especially after 300 rpm the polyethylene foam liner F-217 increases sharply, while the pulp liner levels off, even though all three liners show an increasing trend of immediate removal torque over the whole range of chuck rotation speed.

Figure 12 Speed Effect on IRT at ST 8.9 TIP

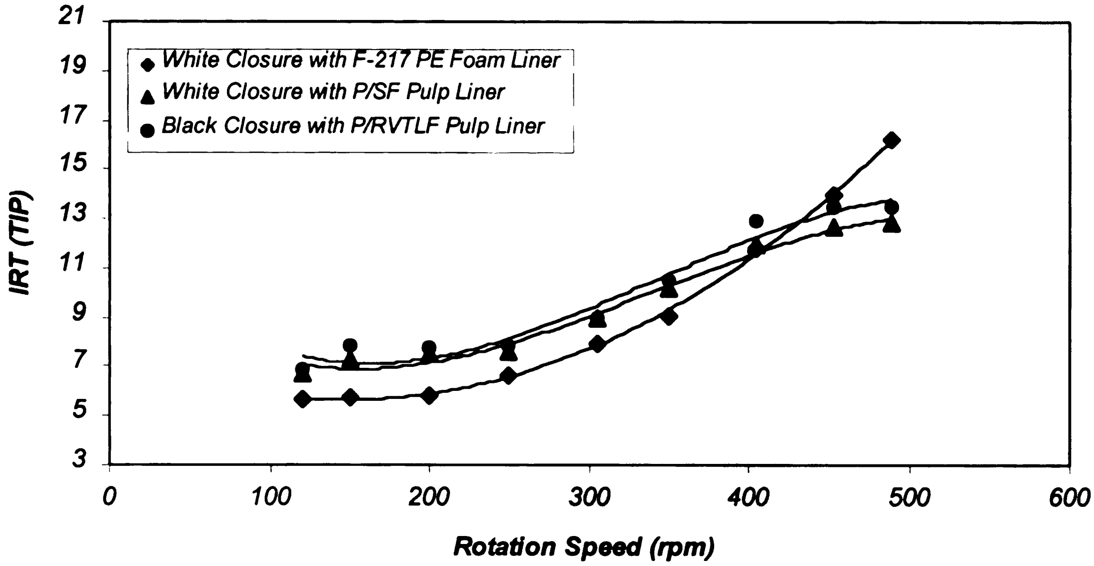


Figure 13 Speed Effect on IRT at ST 11.5 TIP

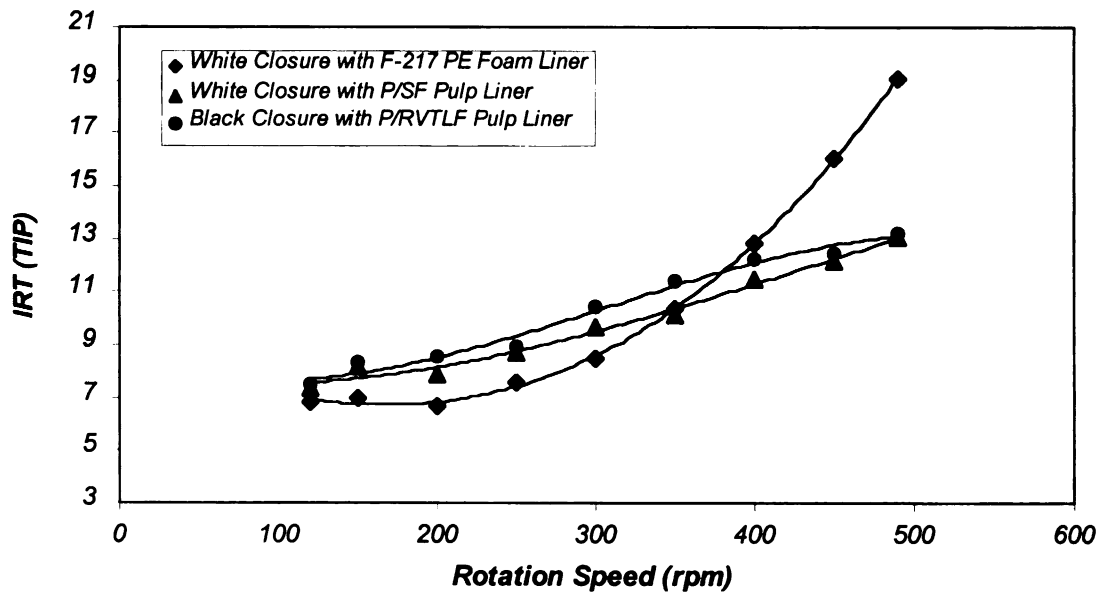


Figure 14 Speed Effect on IRT at ST 14.0 TIP

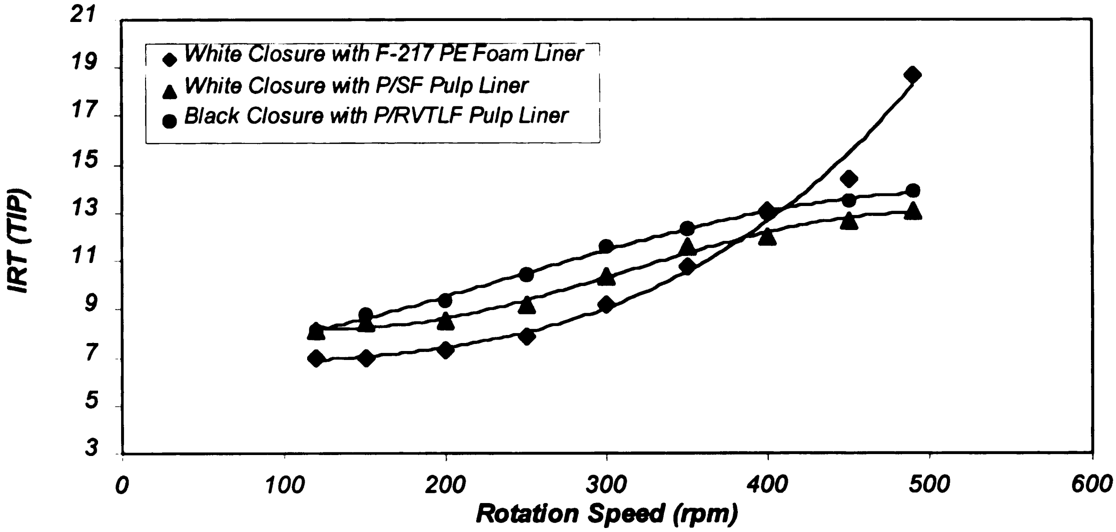


Figure 15 Speed Effect on White Closure with F-217 PE Foam Liner

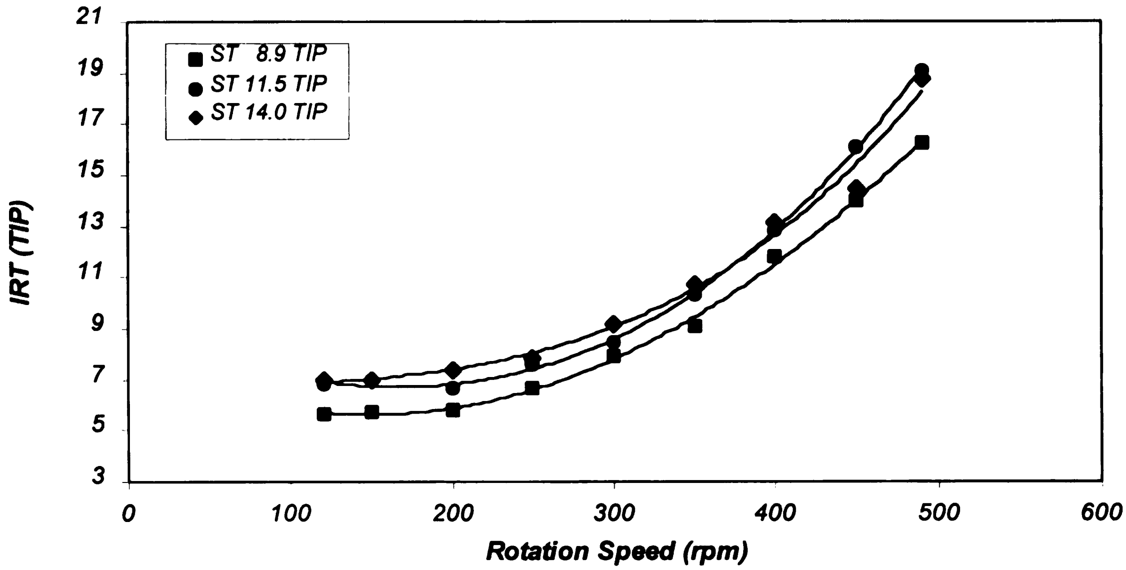


Figure 16 Speed Effect on White Closure with P/SF Pulp Liner

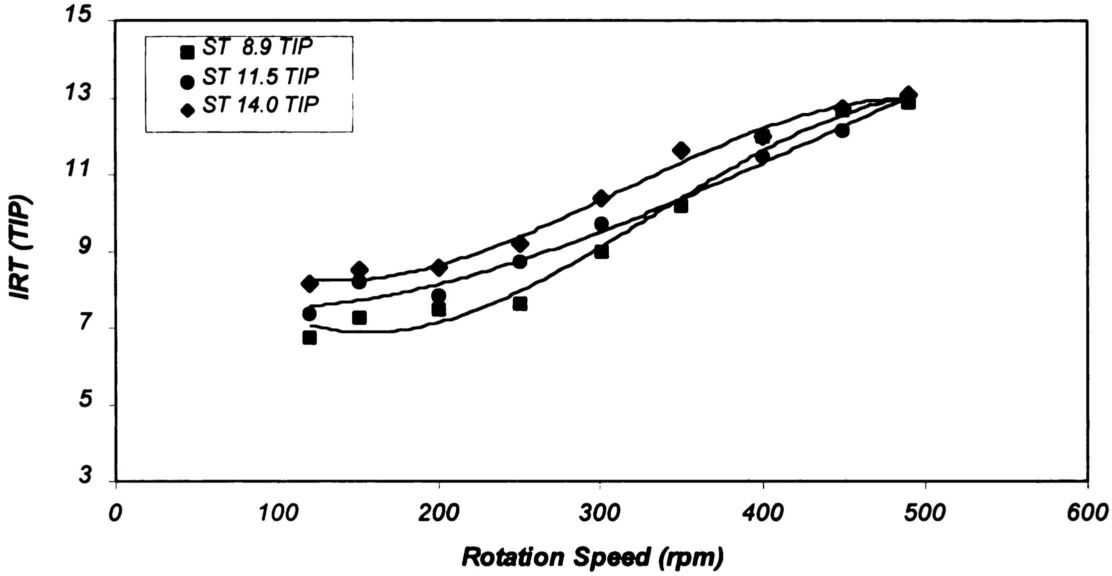
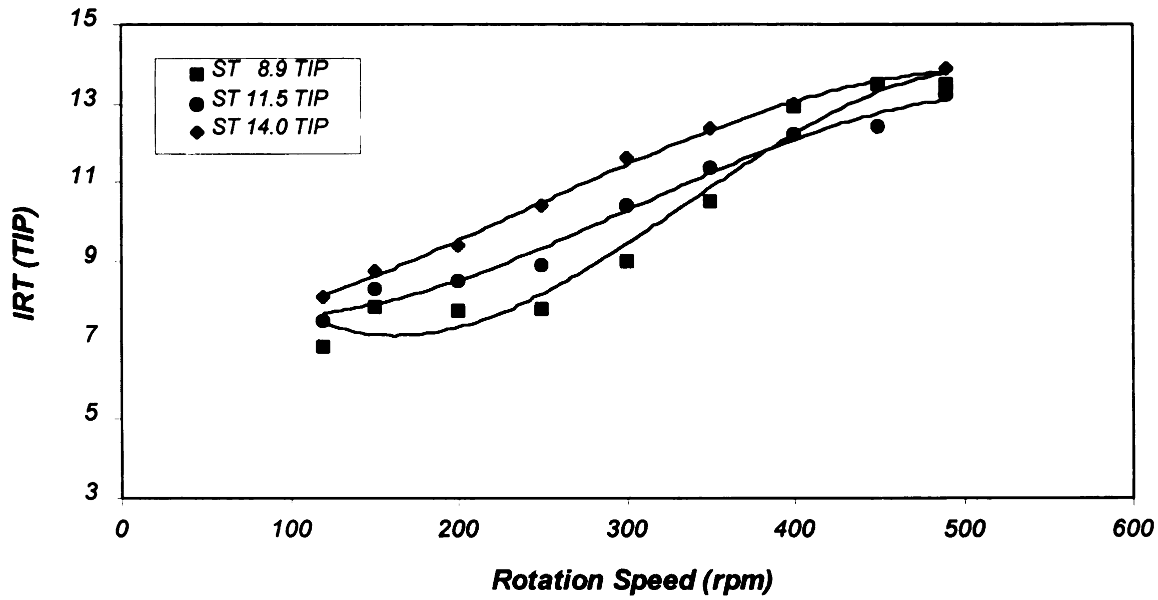


Figure 17 Speed Effect on Black Closure with P/RVTLF Pulp Liner



One-way analyses of variance were run to test the effect of speed for each of nine combinations of static torque and liner. The P-values are in Table 3 below:

Table 3 P-Values of One-Way Analysis of Variance for 9 Speed Levels

Static Torque (TIP)	Liner	P-Value	Statistically Significant?
8.9	F-217 (PE foam)	0.000	Yes
	P/SF (pulp back)	0.000	Yes
	P/RVTLF (pulp back)	0.000	Yes
11.5	F-217 (PE foam)	0.000	Yes
	P/SF (pulp back)	0.000	Yes
	P/RVTLF (pulp back)	0.000	Yes
14.0	F-217 (PE foam)	0.000	Yes
	P/SF (pulp back)	0.000	Yes
	P/RVTLF (pulp back)	0.000	Yes

The increase of immediate removal torque is actually an increase of application torque. This was verified by quantification of the application torque. The application torque can be calculated based on the immediate removal torque, which can be known by the measurements. According to the rule of thumb on removal torque: the immediate removal torque is about 20% to 50% less than application torque. The percentage varies depending on the liner, bottle and closure material and it can be calculated in this case. The data from the impact test can be used for this calculation. During the impact test two levels of impact were used, one impact and 8 impacts. The data from one impact test are needed for this calculation. Insert the cap into the chuck jaw, hold the bottle by hand and screw it into the cap. Turning the bottle until you overcome the magnetic resistance once. In this case the application torque was applied manually by one impulse from the magnetic chuck and it was equal to the static torque set on the magnetic chuck. The immediate removal torque can be obtained by the experimental measurements. The ratio of removal torque to application torque can be calculated as below:

The Ratio of Immediate Removal Torque to Application torque

= Immediate Removal Torque of 1 Impact ÷ Its Corresponding Static Torque. (1)

For F-217 liner,

Static Torque Setting: 9.01 TIP

Average Immediate Removal Torque of 1 Impact Test: 4.38 TIP

The Percent Ratio of Immediate Removal Torque to Application Torque is:

$$4.38 \div 9.01 = 0.49 = 49\ \%$$

Static Torque Setting: 13.88 TIP

Average Immediate Removal Torque of 1 Impact Test: 6.10 TIP

The Percent Ratio of Immediate Removal Torque to Application Torque is:

$$6.10 \div 13.88 = 0.44 = 44\ \%$$

So the average percent ratio of two static torque settings is 46 %. Table 4 shows the ratio of immediate removal torque to application torque of liner F-217 and liner P/SF.

Table 4 Ratio of Immediate Removal Torque to Application Torque of Liner F-217 and Liner P/SF

Index Mark		F-217	P/SF
12	Static Torque (TIP)	9.01	9.01
	IRT (TIP)	4.38	4.84
	Ratio of IRT to Application Torque (%)	49	54
17	Static Torque (TIP)	13.88	13.88
	IRT (TIP)	6.1	7.06
	Ratio of IRT to Application Torque (%)	44	51
Average Ratio of IRT to Application Torque (%)		**46**	**52**

Now we can calculate an estimated application torque that was applied to the bottle during the capper operation.*

* The calculation is based on the assumptions as below:

1. Speed (inertia) has no effect beyond number of impact.
2. There is no effect for impacts beyond 8.
3. There are not more than 8 impacts.

$$\text{Application Torque} = \text{Immediate Removal Torque} \div \text{Ratio of Immediate Removal Torque to Application Torque} \qquad (2)$$

For example, for static torque 8.9 TIP and chuck rotation speed 250 rpm, F-217 liner,

The Average Immediate Removal Torque of 30 bottles: 6.63 TIP

The Application Torque = 6.63 ÷ 46 % = 14.41 TIP

For rotation speed 350 rpm,

The Average Immediate Removal Torque of 30 bottles: 9.08 TIP

The Application Torque = 9.08 ÷ 46 % = 19.74 TIP

So at rotation speed 250 rpm and 350 rpm, the actual application torques are 14.41 TIP and 19.74 TIP. Both of them are much bigger than static torque 8.9 TIP. The application torque of 350 rpm is bigger than 250 rpm. The result of the quantification calculation verifies that higher speed produces higher application torque.

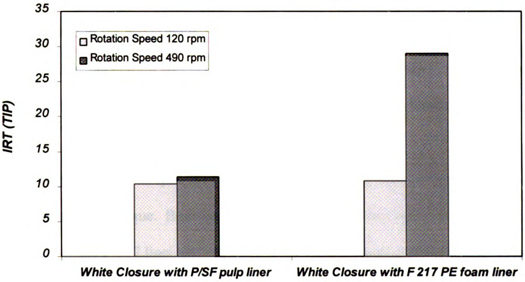
The change of chuck inertia is the main reason for speed effects. As the chuck rotation speed goes up, the chuck has higher inertia, which gives higher application torque. The higher the speed, the bigger the application torque and the immediate removal torque.

Liner Effect

The speed effect curve of polyethylene foam liner F-217 has a very different shape from the speed effect curve of pulp liners. See Figures 11 - 13. As the capping speed goes up, F-217 increases much faster than the pulp liners do and it has a trend of climbing up infinitely. The three pulp liner P/SF curves for three static levels approach a limit (13.5 TIP) at very high speed (490 rpm). (Figures 15 & 16)

In order to see the liner difference in speed effects more clearly, a series of tests was run at two extreme conditions: ST 24.6 TIP, rotation speed 120 rpm and ST 24.6 TIP, rotation speed 490 rpm. The comparison of liner behavior was made only between the two white closure systems: polyethylene foam F-217 liner and pulp back P/SF liner. The test results are shown in Figure 17.

Figure 18 Speed Effect at ST 24.6 TIP



At static torque 24.6 TIP, these two liners behaved differently. At 120 rpm, the immediate removal torques were very close while at 490 rpm they showed huge differences. See Appendix C for the statistical analysis. For F-217, the immediate removal torque at 120 rpm was 10.8 TIP, but at 490 rpm it was 29.0 TIP. For P/SF, the immediate removal torque at 120 rpm was 10.3 TIP, at 490 rpm it was only 11.4 TIP. See Table 5.

Table 5 Comparison of Speed Effect on Immediate Removal Torque for Four Static Torques and Two Liners

Index Mark	Static Torque (TIP)	PE Foam (F-217) (White Closure) Chuck Rotation Speed 120 rpm App. Torque (TIP)	120 rpm IRT (TIP)	490rpm App. Torque (TIP)	490rpm IRT (TIP)	Ratio of 490 to 120 (%)	Pulp Liner (White Closure) Chuck Rotation Speed 120 rpm App. Torque (TIP)	120 rpm IRT (TIP)	490rpm App. Torque (TIP)	490rpm IRT (TIP)	Ratio of 490 to 120 (%)
12	8.9	12.2	6.0	33.2	16.3	273	12.5	6.7	23.8	12.9	191
--	11.7	--	6.8	--	19.1	280	--	7.4	--	13.0	177
17	14.0	15.9	7.0	42.5	18.7	268	16.0	8.1	25.6	13.1	160
27	24.6	--	10.8	--	29.0	270	--	10.3	--	11.4	110

The static torque and immediate removal torque (IRT) value in the above table were measured in the experiment. The application torque value was calculated, not measured. The calculation was demonstrated in Page 33 - 35. Neither the index mark nor the static torque represents the dynamic application torque achieved during machine operation.

At speed level 120 rpm, for both liners, the higher the static torque, the higher the immediate removal torque. Both liners showed elasticity. See Figure 18. At speed level 490 rpm, only the F-217 liner showed an increase of immediate removal torque with the static torque. The pulpback liner P/SF was crushed under ST 24.6 TIP and failed to function elastically. To become inelastic is normal for pulp. See Figure 19. The IRT of P/SF liner leveled off at 13.0 TIP under static torque 8.9 TIP, 11.5 TIP and 14.0 TIP. Its immediate removal torque dropped to 11.4 TIP dramatically at static torque 24.6 TIP. The percent change of immediate removal torque remained around 270 % for F-217 over a range of four static torques, while for P/SF, it decreased from 190% to 110%.

Figure 19 IRT Behavior of Two Liner Systems under Four Static Torques at Rotation Speed 120 rpm

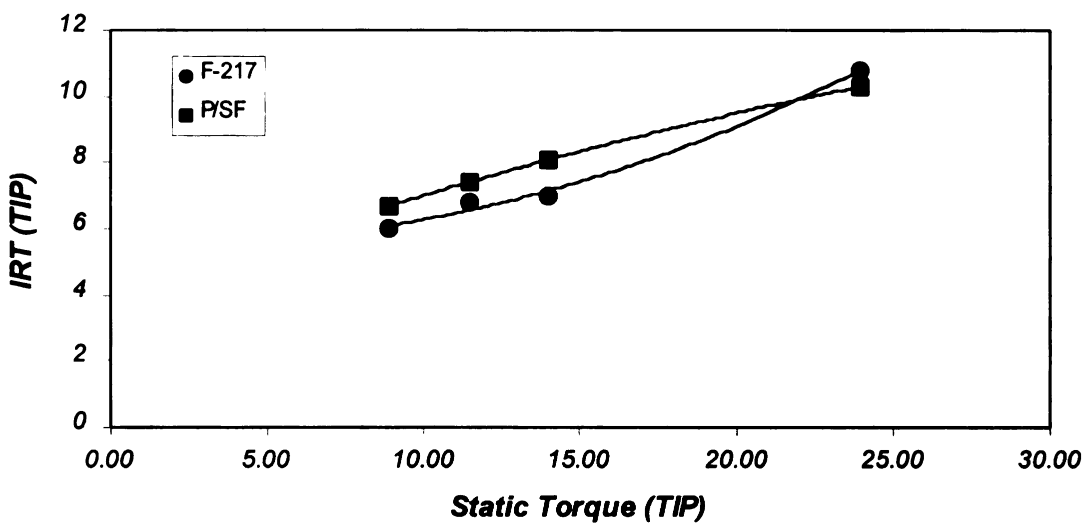
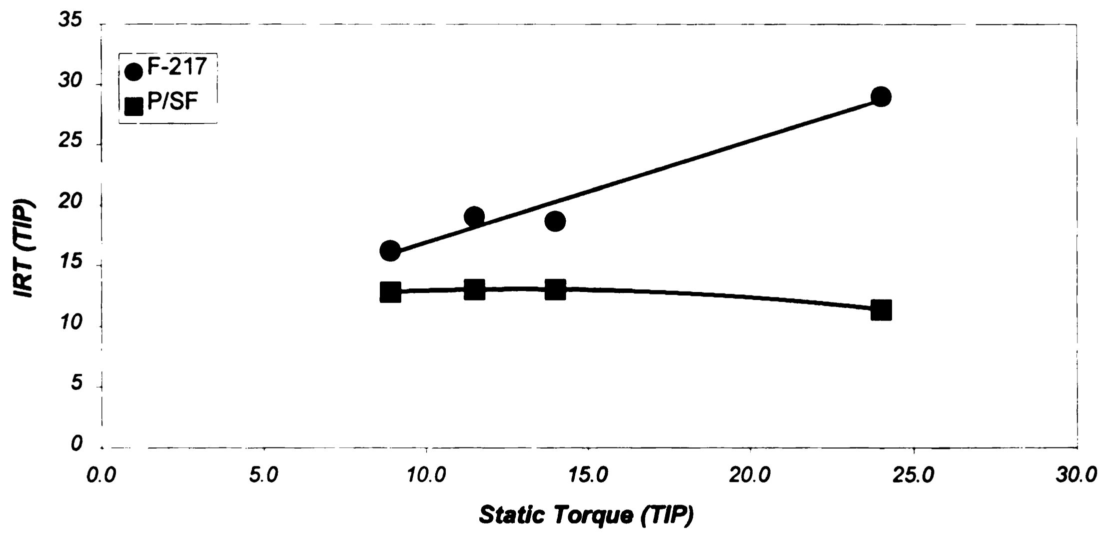


Figure 20   IRT Behavior of Two Liner Systems under Four Static Torques at Rotation Speed 490 rpm



These differences are due to the different physical properties of the two liner materials. Polyethylene foam F-217 is a highly viscoelastic material, which is very sensitive to speed. The higher the speed, the higher the tensile and compression strength. The big increase of immediate removal torque is the result of viscoelasticity and chuck inertia working in combination. Pulps have very limited elasticity. Increasing of chuck inertia caused by increased rotation speed is the major factor in the result of immediate removal torque increasing. At low static torque and low capping speed, the pulp liner did show a little elasticity and the immediate removal torque was increasing gradually and slowly. Because of lack of viscoelasticity, pulps are not as sensitive to speed as the polyethylene foams are, so at high speed levels, the speed effect on immediate removal torque was not obvious. Instead, it was diminishing. For the same reason, pulps tend to crush at very high static torque like 24.6 TIP, so the liner could not function properly and the immediate removal torque decreased even though the chuck rotation speed was very high (490 rpm).

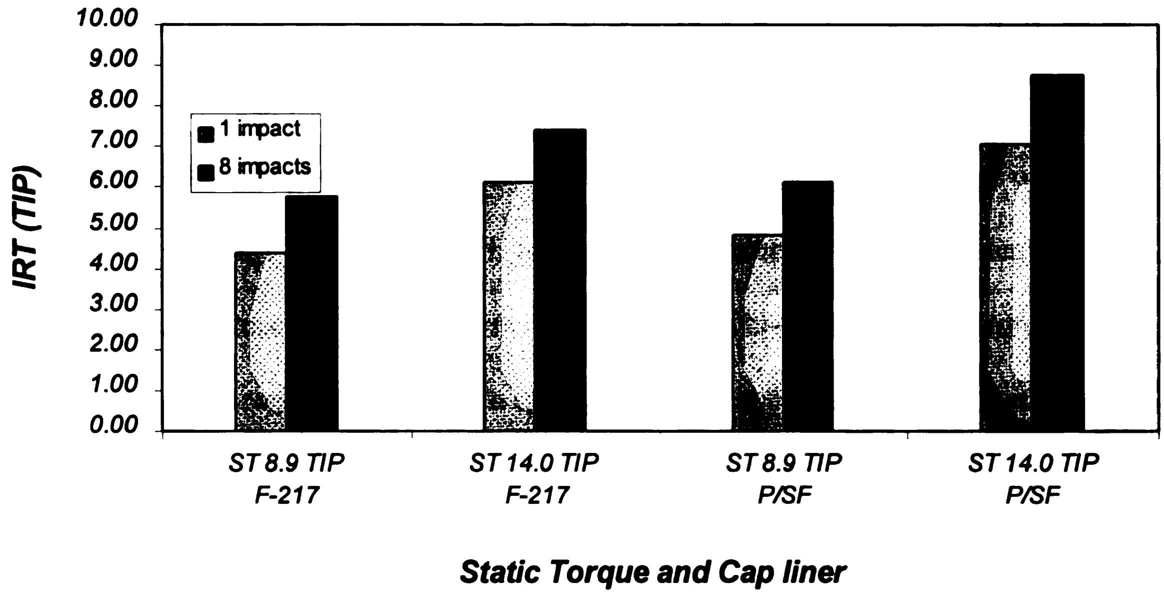
Impact Effect

The immediate removal torque of 8 chuck impacts is about 26% greater than it is for 1 chuck impact. The data shows a consistent result for static torque level 8.9 TIP and 14.0 TIP and two different liners. See Table 6 and Figure 20. This result conforms to common sense and it is statistically significant.

Table 6 Impact Effect on Immediate Removal Torque

Liner	Static Torque (TIP)	IRT of 1 Impact (TIP)	IRT of 8 Impacts (TIP)	% Change of IRT	Average of % Change
F-217	8.9	4.38	5.75	31%	26%
	14.0	6.10	7.40	21%	
P/SF	8.9	4.84	6.14	27%	26%
	14.0	7.06	8.74	24%	

Figure 21 Impact Effect on IRT



Data Validation

Discarding unreasonably low data does not confound the results. In fact, that is what capper operators do on the real packaging line. They have a quality control program to monitor the immediate removal torque. Because the loose cap issue is beyond the machine capability in many cases, people on real filling/capping lines may get a wide range of immediate removal torque. When the loose cap or excessive low torque occurs, they usually reject these products for quality control purposes. For this project, ignoring these unreasonable values lowered the data mean value a little bit, but certainly did not confound the results.

SUMMARY AND CONCLUSIONS

Immediate Removal Torque shows a pattern of increase over the range of 120 rpm to 490 rpm. This is true in both PE foam liner system and pulp back system. Higher rotation speed produces higher chuck inertia, which gives higher application torque. When the capper is working at a certain speed, the actual application torque that it puts on the closure-bottle system is no longer the same as static torque. The application torque increases because the chuck has more inertia as its rotation speed increases. Eventually it produces higher immediate removal torque.

Foam liner (F-217) has a very different increasing pattern from pulp liner. Foam liner F-217 is more affected by speed than pulp liner. F-217 is a highly viscoelastic material, which is very sensitive to speed. At high speed, the viscoelastic material shows higher compression stess. It maintains elasticity, then shows relaxation. The big increase of Immediate Removal Torque is the result of viscoelasticity and chuck inertia working in combination.

Pulps have very limited elasticity. Speed effect is the major factor in the result of IRT increasing. Under low static torque, pulp liner shows a little elasticity. As the static torque goes up, the elasticity decreases, and so does the increase of IRT. The higher the static torque, the less the speed effect in pulp liner. At high application speed pulp liner has almost level performance on the graph. The speed effect is diminished, because under high rotation speed and high static torque the pulps is crushed instead of performing elastically.

Based on this research, the application torque varies with the capping speed. If the line speed or the capper speed changes, the static torque needs to be adjusted in order to achieve the same application torque. Also a different application torque can be achieved by changing the speed of rotary capper while accommodating the line speed instead of resetting the static torque. For different liner materials, the adjustment should be different. For a viscoelastic material like F-217 liner, many adjustments on machine speed or the production speed can be made to achieve the same target torque and the machine capability can be increased because of that. But for non-viscoelastic material like the pulp liner used in this project, although there are benefits from the chuck speed effect, the machine adjustment is limited. So to increase the speed of a filling / capping line while maintaining a high quality target torque, the capper needs to be adjusted not only on the rotation speed, but also on the static torque based on the characteristics of the liner material.

Some people may ask that why not just use the maximum rotation speed for the maximum immediate removal torque regardless of pulp vs. plastic. The answer is high speed does not necessarily mean high quality torquing. Because of the speed effect, running capper at maximum speed could cause excessively high immediate removal torque and usually this high torque is far beyond the range of target torque. It could make the closure very difficult to remove. Obviously, this is not so called "proper torquing". This thesis should not make the wrong impression -- the higher the speed, the better the torquing quality. Instead, we want the readers to understand that an ideal target torque can be achieved by proper machine adjustments including rotation speed adjustment.

For future study, the alignment of the closure thread start and bottle thread start needs a more in-depth investigation. Also to solve the "loose cap" problem, a similar research on "head descent and torque control dependent" type of rotary capper would be very helpful and would give us more accurate data and a more consistent result. The same research is recommended for child-resistant closure systems. For this type of closure low immediate removal torques can lead to violation of regulatory requirements and recall. High immediate removal torques can render child resistant caps impossible to remove. Finally, speed effect testing on the in-line capper would be worth doing because this type of capper is even more popular than the rotary capper in some industries.

APPENDICES

Appendix A

This is a verbatim copy of pertinent parts of the operating guide for the Zalkin Semi-Automatic Capping Machine

APPENDIX A

ZALKIN SEMI-AUTOMATIC CAPPING MACHINE TYPE TM3 OPERATING GUIDE

GENERAL INFORMATION

Renowned for their simplicity and sturdiness, the ZALKIN semi-automatic capping machines can be used to apply aluminum seals (short or long flange type), tear-off caps or lead capsules, as well as plastic screw closures.

The capping head moves vertically, as the bottle rest remains in position.

These machines can be placed on a table, on a bench, or on a caster mounted stand (available at additional cost), in order to move them more easily.

BEWARE:

When starting the machine, check that the head revolves in the direction shown by an arrow on the perpex guard cover (clockwise). If not, invert the two wires (marked 2 and 4), inside the contactor.

WARNING!

FAILURE TO PERFORM ROUTINE CHECKING AS DESCRIBED CAN RESULT IN SUBSTANDARD APPLICATIONS, LEAKERS AND PREMATURE CLOSURE RELEASE.

MACHINE HEIGHT ADJUSTMENT AND BOTTLE SIZE CHANGE
(machine fitted with a screw capping head)

In case of a bottle size change, adjust machine height, using the upper handwheel. Proceed as follows:

- Stop the machine when the head is at its lowest point. (This can be obtained by turning the sealing head by hand rather than using the electric motor.)
- Loosen the locking screw on lower collar.
- Place a bottle with a cap on the bottle rest, under the screw capping head.
- Adjust the screw capping head height, by turning the handwheel. A correct setting is achieved when jaws enter the chuck bell by 4 mm (unless otherwise stated), the cap is tightly screwed onto the bottle.
- Tighten the locking screw firmly onto lower collar.

BZ 2 MAGNETIC SCREW CAPPING HEAD

The ZALKIN magnetic capping head uses two rings of permanent magnets: an inner ring attached to the head spindle and an outer ring attached to a vertically adjustable housing.

The magnetic head, because of its magnetic force field drive, does not rely on any mechanical action or surface friction for torque control.

The type "BZ 2" capping head includes:

- A torque control assembly,
- A chuck with jaws, which picks up the caps and places them onto the bottles.

It is designed and built so it requires very little routine maintenance under normal operating conditions. However, it is very important to protect the head from direct exposure to steam and chemical cleaning. It should not be submerged in water or any liquid. Exterior cleaning should be limited and accomplished by wiping with rags or towels moistened with water, if needed, to remove dried product or dirt.

An inspection of each head should be performed daily: check no foreign material (which may prevent the sensor pin or the jaws from moving freely) has entered the chuck; chuck should be tight in the head; also check the static torque.

Lubrication should consist of a thin film of a high quality food grade lubricant: slide cylinder should be lubricated frequently. Once or twice a month (depending on how long the machine has been run) remove the head lower body and clean jaws and plunger thoroughly.

TYPE BZ 2 MAGNETIC CAPPING HEADS USE AND MAINTENANCE

The ZALKIN BZ 2 heads are equipped with permanent magnets and must be handled with special care. VERY IMPORTANT:

AVOID

1. STEAM
2. TEMPERATURES ABOVE 100° CELCIUS
3. CHEMICALS

Overlooking these recommendations will alter the magnetic effects and therefore, the torques!!!

MACHINE HEIGHT & COMPRESSION ADJUSTMENT

Our capping machines are usually fitted with a setting gauge. The machine height setting is correct when jaws enter the chuck bell by 4 mm (unless otherwise stated), the cap being tightly screwed onto the bottle.

BZ 2 MAGNETIC SCREW CAPPING HEAD ADJUSTMENT OR REPLACEMENT OF CHUCK WITH JAWS

1. Jaws tightening is easily increased or decreased by compressing or releasing the return spring with the lock nuts. Tightening should be increased if caps turn in the jaws and decreased if jaws deform the caps.
2. Depending on cap diameter, chuck with jaws should be replaced. Unscrew chuck (right hand thread using the large spanner wrenches provided. Jaws may be made of stainless steel with teeth or smooth polyurethane inserts. In some cases, the same chuck can be used for caps which diameter differs, by changing the plastic inserts only.

SETTING OF STATIC TORQUE

Static torque is the head or torsionnal force as measured when stationary only by hand.

Place the head on the plate of the torque meter, with the chuck upward. To measure torque, slowly rotate chuck by means of the special wrench (sleeve with teeth, see attached drawing) in a clockwise direction: the torque is then read directly from the meter.

If torque requires to be adjusted, proceed as follows:

1. Unscrew the locking screw on the housing of the chuck.
2. To increase torque, screw outer magnet ring. Unscrew it to decrease torque.

   Minimum torque: approx. 5 inch / pounds

   Maximum torque: approx. 38 inch / pounds

NOTE: The position marks (4 distances) provided on the setting gauge are for movement reference only.

3. Tighten the locking screw tightly.

Appendix B

This is the testing procedure developed by the author for this experiment.

APPENDIX B

TESTING PROCEDURE

1. Take off the capping head and set the static torque.
2. Measure the static torque on the digital torque tester and record the data.(10 times)
3. Install the capping head back on the machine.
4. Adjust the height of the capping head (chuck) and the bottle holder.
5. Adjust the size of the bottle holder and center it.
6. Set the running mode to "continuous" and let the machine run continuously for a few minutes.
7. Use the non-contact tachometer to measure the chuck rotation speed.
8. While the machine is running, change the chuck rotation speed by turning the wheel on the back of the motor. Keep measuring the speed until it is running at target speed.
9. Set the running mode to "single run" (The machine stops every time after one application is done.).
10. Test 30 bottles for each liner. Insert the cap into the magnetic chuck, place the bottle in the holder, then turn on the machine. After the application the machine stops automatically. Take out the bottle and set it aside.
11. After one set of sample is done, wait for 15 minutes. The bottles should be placed in order.

12. Remove the closure smoothly on the digital torque tester and record the data. Start with the first bottle applied and go by the order of application. The cap should be removed by bare hand* at the rotation speed of second hand of clock.

    *When F-217 liner was tested at rotation speed 450 rpm and 490 rpm, the cap was not removed by bare hand. Instead, a rubber glove was used to improve the grip. Wearing a rubber glove does not affect the measurements of removal torque. It should produce the same result as working with bare hand.

13. At each speed level 3 different liner materials are tested. The sample size is 30 bottles. The actual rotation speed was set within the range of target speed $\pm$ 10rpm.
14. Run the statistical analysis on Minitab 11.2.
15. After 3 liner systems are tested, change the speed level and run another 3 sets of test by repeating step 6 - 12.
16. When all the speed levels under one static torque are done, move on to second static torque by following step 1 - 12. In total 3 static torque level were tested. See Table 1 for test condition.

Appendix C

These are the one way ANOVA results for all variables in the experiment.

APPENDIX C

STATISTICAL ANALYSIS RESULTS

SPEED EFFECT

Static Torque Level: 8.9 TIP
Liner Material: F-217

One-Way Analysis of Variance

```
Analysis of Variance
Source       DF        SS        MS        F        P
Factor        8   3638.05    454.76   201.99    0.000
Error       261    587.60      2.25
Total       269   4225.65
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Speed         N      Mean     StDev  ------+---------+---------+---------+
120          30     5.960     1.224   (-*-)
150          30     5.737     1.217   (*-)
200          30     5.813     0.723   (-*)
250          30     6.630     0.892     (-*)
300          30     7.930     1.189         (-*)
350          30     9.080     1.283            (-*)
400          30    11.800     1.448                    (-*)
450          30    13.957     2.109                          (-*)
490          30    16.250     2.522                                 (*-)
                                     ------+---------+---------+---------+
Pooled StDev =      1.500                   7.0      10.5      14.0      17.5
```

Static Torque Level: 8.9 TIP
Liner Material: P/SF

One-Way Analysis of Variance

```
Analysis of Variance
Source     DF        SS        MS        F        P
Factor      8   1504.07    188.01   148.39    0.000
Error     261    330.69      1.27
Total     269   1834.76
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Speed       N      Mean     StDev  ---------+---------+---------+-------
120        30     6.737     1.121   (-*-)
150        30     7.253     0.846     (-*-)
200        30     7.083     1.031    (-*-)
250        30     7.610     0.703       (-*-)
300        30     8.947     1.080              (-*-)
350        30    10.187     1.343                    (-*-)
400        30    11.970     1.019                             (-*-)
450        30    12.653     1.659                                (-*-)
490        30    12.850     1.054                                 (-*-)
                                   ---------+---------+---------+-------
Pooled StDev =    1.126                   8.0      10.0      12.0
```

Static Torque Level: 8.9 TIP
Liner Material: P/RVTLF

One-Way Analysis of Variance

```
Analysis of Variance
Source     DF        SS        MS        F        P
Factor      8   1752.36    219.05   184.12    0.000
Error     261    310.50      1.19
Total     269   2062.86
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Speed       N      Mean     StDev  -----+---------+---------+---------+-
120        30     6.847     0.987   (*-)
150        30     7.843     0.730       (*-)
200        30     7.750     1.212      (-*-)
250        30     7.813     0.966       (*-)
300        30     9.013     0.825           (-*-)
350        30    10.497     1.537                 (-*-)
400        30    12.923     1.081                           (-*)
450        30    13.467     1.012                             (-*)
490        30    13.493     1.250                             (-*-)
                                   -----+---------+---------+---------+-
Pooled StDev =    1.091               7.5      10.0      12.5      15.0
```

Static Torque Level: **11.5 TIP**
Liner Material: **F-217**

One-Way Analysis of Variance

```
Analysis of Variance
Source     DF         SS         MS         F        P
Factor      8    4911.03     613.88    145.91     0.000
Error     261    1098.05       4.21
Total     269    6009.08
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Speed        N       Mean     StDev  ------+---------+---------+---------
+
120          30      6.807     1.641   (-*-)
150          30      6.963     1.934    (*-)
200          30      6.640     1.202   (-*)
250          30      7.560     0.869     (-*-)
300          30      8.487     1.775       (-*-)
350          30     10.360     1.570            (-*-)
400          30     12.823     2.475                  (-*-)
450          30     16.067     2.930                          (-*-)
490          30     19.077     2.984                                  (-*-)
                                   ------+---------+---------+---------+
Pooled StDev =    2.051                8.0      12.0      16.0     20.0
```

Static Torque Level: **11.5 TIP**
Liner Material: **P/SF**

One-Way Analysis of Variance

```
Analysis of Variance
Source     DF         SS         MS         F        P
Factor      8     974.86     121.86     55.54     0.000
Error     261     572.69       2.19
Total     269    1547.55
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Speed        N       Mean     StDev  ------+---------+---------+---------+
120          30      7.353     1.343  (--*-)
150          30      8.170     1.945      (--*--)
200          30      7.850     0.844     (-*--)
250          30      8.687     0.524         (-*--)
300          30      9.713     1.040              (--*-)
350          30     10.153     1.849                (--*-)
400          30     11.473     1.720                       (-*--)
450          30     12.137     1.780                          (--*-)
490          30     13.030     1.594                              (--*--)
                                   ------+---------+---------+---------+
Pooled StDev =    1.481                8.0      10.0      12.0     14.0
```

Static Torque Level: 11.5 TIP
Liner Material: P/RVTLF

One-Way Analysis of Variance

```
Analysis of Variance
Source      DF        SS        MS         F        P
Factor       8   1052.88    131.61     42.10    0.000
Error      261    815.96      3.13
Total      269   1868.84
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Speed        N      Mean     StDev ------+---------+---------+---------
+
120         30     7.473     1.087 (--*---)
150         30     8.300     1.480     (---*--)
200         30     8.520     0.914      (---*--)
250         30     8.923     1.791        (---*--)
300         30    10.393     1.643                (--*--)
350         30    11.390     1.712                     (--*--)
400         30    12.220     1.814                         (--*--)
450         30    12.453     2.589                          (--*--)
490         30    13.220     2.259                              (--*--)
                                   ------+---------+---------+---------+
Pooled StDev =     1.768                 8.0      10.0      12.0      14.0
```

Static Torque Level: 14 TIP
Liner Material: F-217

One-Way Analysis of Variance

```
Analysis of Variance
Source      DF        SS        MS         F        P
Factor       8   3992.48    499.06    106.33    0.000
Error      261   1225.01      4.69
Total      269   5217.49
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Speed        N      Mean     StDev -----+---------+---------+---------+-
120         30     6.980     1.279  (*-)
150         30     6.987     1.544  (*-)
200         30     7.330     1.330  (-*-)
250         30     7.870     0.891    (-*-)
300         30     9.157     1.412       (-*-)
350         30    10.727     1.593           (-*-)
400         30    13.113     2.588                 (-*-)
450         30    14.427     3.459                    (-*-)
490         30    18.707     3.530                               (-*-)
                                   -----+---------+---------+---------+-
Pooled StDev =     2.166                3.0      12.0      16.0      20.0
```

Static Torque Level: 14 TIP
Liner Material: P/SF

One-Way Analysis of Variance

```
Analysis of Variance
Source     DF        SS        MS        F        P
Factor      8    901.91    112.74    64.73    0.000
Error     261    454.56      1.74
Total     269   1356.47
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Speed       N      Mean     StDev  ---+---------+---------+---------+---
120        30     8.140     1.097   (--*--)
150        30     8.493     1.276     (--*--)
200        30     8.557     0.895      (-*--)
250        30     9.163     0.601         (--*--)
300        30    10.360     1.419                 (--*--)
350        30    11.597     1.602                         (-*--)
400        30    12.013     1.426                           (--*--)
450        30    12.700     1.554                               (--*--)
490        30    13.063     1.627                                  (--*--)
                                   ---+---------+---------+---------+---
Pooled StDev =    1.320             8.0       9.6      11.2      12.8
```

Static Torque Level: 14 TIP
Liner Material: P/RVTLF

One-Way Analysis of Variance

```
Analysis of Variance
Source     DF        SS        MS        F        P
Factor      8   1105.82    138.23    81.82    0.000
Error     261    440.95      1.69
Total     269   1546.76
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Speed       N      Mean     StDev  --+---------+---------+---------+----
120        30     8.077     1.113  (-*--)
150        30     8.747     1.075     (--*-)
200        30     9.377     0.683         (-*-)
250        30    10.387     0.636              (-*-)
300        30    11.623     1.059                    (-*-)
350        30    12.357     1.209                       (--*-)
400        30    12.990     1.420                           (-*-)
450        30    13.480     1.261                             (-*--)
490        30    13.880     2.398                               (-*--)
                                   --+---------+---------+---------+----
Pooled StDev =    1.300            8.0      10.0      12.0      14.0
```

LINER EFFECT

Static Torque Level: 25 TIP
Speed Level: 120

One-Way Analysis of Variance

Analysis of Variance

Source	DF	SS	MS	F	P
Factor	1	3.13	3.13	1.06	0.309
Error	58	171.96	2.96		
Total	59	175.09			

```
                                       Individual 95% CIs For Mean
                                       Based on Pooled StDev
Liner       N      Mean     StDev   -------+---------+---------+---------
F-217      30    10.773     2.049             (-----------*------------)
P/SF       30    10.317     1.316    (-----------*------------)
                                     -------+---------+---------+---------
Pooled StDev =    1.722                     10.00     10.50     11.00
```

Static Torque Level: 25 TIP
Speed Level: 490

One-Way Analysis of Variance

Analysis of Variance

Source	DF	SS	MS	F	P
Factor	1	4665.8	4665.8	205.14	0.000
Error	58	1319.1	22.7		
Total	59	5984.9			

```
                                       Individual 95% CIs For Mean
                                       Based on Pooled StDev
Liner       N      Mean     StDev   ----+---------+---------+---------+--
F-217      30    29.040     6.505                                (--*--)
P/SF       30    11.403     1.780   (--*--)
                                    ----+---------+---------+---------+--
Pooled StDev =    4.769               12.0      18.0      24.0      30.0
```

Static Torque Level: 25 TIP
Liner Material: F-217

One-Way Analysis of Variance

```
Analysis of Variance
Source      DF        SS        MS        F        P
Factor       1    5005.1    5005.1   215.19    0.000
Error       58    1349.0      23.3
Total       59    6354.1
                                    Individual 95% CIs For Mean
                                    Based on Pooled StDev
Speed        N      Mean     StDev  -----+---------+---------+---------+-
120         30    10.773     2.049  (--*--)
490         30    29.040     6.505                                (--*--)
                                    -----+---------+---------+---------+-
Pooled StDev =     4.823              12.0      18.0      24.0      30.0
```

Static Torque Level: 25 TIP
Liner Material: P/SF

One-Way Analysis of Variance

```
Analysis of Variance
Source      DF        SS        MS        F        P
Factor       1     17.71     17.71     7.23    0.009
Error       58    142.11      2.45
Total       59    159.82
                                    Individual 95% CIs For Mean
                                    Based on Pooled StDev
Speed        N      Mean     StDev  -+---------+---------+---------+-----
120         30    10.317     1.316  (-------*--------)
490         30    11.403     1.780                 (-------*-------)
                                    -+---------+---------+---------+-----
Pooled StDev =     1.565           9.80     10.50     11.20     11.90
```

IMPACT TEST

Static Torque Level: 8.9 TIP
Liner Material: F-217

One-Way Analysis of Variance

```
Analysis of Variance
Source     DF        SS        MS        F        P
Factor      1    28.428    28.428   155.72    0.000
Error      58    10.588     0.183
Total      59    39.016
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Impact No.  N      Mean     StDev  ------+---------+---------+---------+
8          30    5.7533    0.4783                              (--*--)
1          30    4.3767    0.3692  (---*--)
                                   ------+---------+---------+---------+
Pooled StDev =   0.4273                4.50      5.00      5.50    6.00
```

Static Torque Level: 8.9 TIP
Liner Material: P/SF

One-Way Analysis of Variance

```
Analysis of Variance
Source     DF        SS        MS        F        P
Factor      1   25.3500   25.3500   289.20    0.000
Error      58    5.0840    0.0877
Total      59   30.4340
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Impact No.  N      Mean     StDev  ------+---------+---------+---------+
8          30    6.1400    0.3244                             (-*-)
1          30    4.8400    0.2647   (-*-)
                                   ------+---------+---------+---------+
Pooled StDev =   0.2961                5.00      5.50      6.00    6.50
```

Static Torque Level: 14 TIP
Liner Material: F-217

One-Way Analysis of Variance

```
Analysis of Variance
Source      DF        SS        MS        F        P
Factor       1    25.480    25.480    37.98    0.000
Error       58    38.910     0.671
Total       59    64.390
                                    Individual 95% CIs For Mean
                                    Based on Pooled StDev
Impact No.  N       Mean     StDev  ----+---------+---------+---------+--
8          30     7.4000    0.9896                      (----*----)
1          30     6.0967    0.6020   (----*----)
                                    ----+---------+---------+---------+--
Pooled StDev =    0.8191              6.00      6.60      7.20      7.80
```

Static Torque Level: 14 TIP
Liner Material: P/SF

One-Way Analysis of Variance

```
Analysis of Variance
Source      DF        SS        MS        F        P
Factor       1    42.673    42.673   250.83    0.000
Error       58     9.867     0.170
Total       59    52.540
                                    Individual 95% CIs For Mean
                                    Based on Pooled StDev
Impact No.  N       Mean     StDev  -----+---------+---------+---------+-
8          30     8.7433    0.4636                             (--*-)
1          30     7.0567    0.3540  (--*-)
                                    -----+---------+---------+---------+-
Pooled StDev =    0.4125               7.20      7.80      8.40      9.00
```

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