MULTIDISCIPLINARY RESEARCH INSTITUTE INDIA

International Journal of Advanced Scientific Research and Engineering Trends

ISSN: 2456-0774

Volume 10 Issue 2 (2026) | Pages: 110-118

# Optimization of Washer Design to avoid Fastener stuck in Rear Driveshaft Flanged Assembly

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**Peer Review Information**

***Type***: *Article*
***Received***: *08 Dec 2025*
***Revised***: *30 Dec 2025*
***Accepted***: *02 Feb 2026*
***Published***: *25 Feb 2026*

**Abstract**

Construction of the rear driveshaft flange has recorded multiple incidences of washer binding when M10 bolts are tightened. Most of the binding occurrences happened in the 8¼ turns of the bolt, which was associated with delays, thread damage, compromised safety, and prolonged cycle completion times. This paper presents a washer redesign with a larger center hole, improved tighter tolerance manufacturing, and a better surface finish. The redesign eliminates binding, improves response to assembly tooling, and reduces cycle time—all without additional cost. It was successfully tested with both single and dual spindle drivers, as well as passing torque failure and bolt slip tests. The threaded fasteners' contact interfaces and their interactions exhibit complex tribology which makes the torque reading during the tightening process highly variable and, at times, contradictory. For screw threads, particularly those that exhibit variable friction during tightening, morphologies have been identified that influence the fastening process tribologically. The tribological context of surface finish and its effect on manufacturing has been a key focus in the study of friction.

**Keywords:** Driveshaft Flange; Washer Binding; Assembly Optimization; M10 Bolt; Manufacturing Defects; Dual Spindle Tool; Torque Application

## How to Cite This Article

Choudhury, R. R., & Waghmare, S. U. (2026). Optimization of washer design to avoid fastener stuck in rear driveshaft flanged assembly. *International Journal of Advanced Scientific Research and Engineering Trends,* 10(2), 110-118.

## Introduction

Automotive assembly requires precision and repeatability to achieve the proper torque and secure joint connections. During the assembly of driveshaft flanges, M10 bolts are tightened with both single and dual spindle tools. However, production reports have shown that washer binding has been a common occurrence that has caused interruptions and quality issues. This paper discusses the causes of the binding issue and presents a redesigned washer that resolves the issue without altering the tools or components. Threaded assemblies typically consist of a bolt, a nut, and one or more washers. It is often understood that the distinctions between a screw and a bolt are commonly misunderstood. Many of us, including some experts, tend to conflate these two terms. In most cases, that is acceptable; however, for a technical or scientific document, some important points must be noted. While there is a practical and technical distinction between bolts and screws, there is often a shared engineering characteristic. In the definition proposed, bolts are used to fasten two unthreaded parts together using a nut.Screws serve the purpose of fastening parts where at least one component possesses an internal thread, which may also be formed during the screw's insertion. Threaded fasteners can be characterized as bolts or screws based on how the fastener is engineered, as well as its intended function. Bolts are more often used in the construction of bolted joints; these are some of the most widely used components found in the design and assembly of machinery. Bolted joints consist of fastener components that trap and unite other components and are retained through the action of screw thread coupling. However, this custom may vary from what is typically understood and practiced in the fastener sector regarding the differences between bolts and screws. In ISO 1891 Fasteners—Terminology and nomenclature, a hexagon bolt is defined as having a plain unthreaded shank, while a hexagon screw is one that has a thread up to the head. This is the ISO classification, and it is what the industry understands and uses most.

In the industry, there are numerous possibilities for the design of bolted joints. Among the possibilities, two are especially noteworthy: so called tension joints and shear joints. In this study, we will explore tension joints, while for numerous scientific reasons, we will not explore shear joints. In a tension joint, the designed and shaped components are intended to transfer the strain being applied to the joint, through the compressive members. Further, for scientific reasons, the elastic plastic deformation of the assemblage is ignored, and it is presumed that there is an appropriate equilibrium of the joint and bolt elastic stiffness. The assemblage is properly configured when the external tension force that is trying to separate the joint, does not exceed the clamping force. If the external tension force is applied to the joint, it will ultimately lead to the separation of the clamped portions, and then they will be free to move relative to each other, which is certainly undesirable.Regardless of the extensive application of this type of fastener, understanding of the most rudimentary of frictional phenomena between different contacting surfaces remains almost non-existent.

Two basic parameters of industrial assembly are the type of method of fastening and the amount of assembly torque used in the operations of contraction. The functional characteristics of the contacting bodies affect the assembly torque of the screw fasteners. In order to better comprehend the intricacy of frictional phenomena, a number of various parameters are examined. Thus, the process of friction deserves detailed analysis since the empirical mechanics of the contacting surfaces govern the operation of screw fasteners.

Despite the threaded fasteners industry being viewed as somewhat conservative when it comes to new solutions and materials, the industry continues to come up with new, innovative ideas and materials. While new advancements in industrial manufacturing are able to grow quickly, there is little information available to the public due to proprietary and competitive reasons. This motivates us, in part, to continue sharing our findings and experience. With this in mind, we hope to gain the position of collecting feedback information from the scientific and industrial communities. From all indications, it seems that the advancement of the bolted joints will not come to a halt. In fact, the bolted joints of the 21st century may not yet exist. A wide range of applications exist for threaded fasteners. These range from the specific requirements of some medical applications (orthopedic and spinal surgery) to specific requirements in the joining technology of mechanical components (automotive industry, lightweight structures, and in particular, components for automated assembly) and up to the extreme requirements of aerospace technology [1-4].Each of these areas has its specific requirements for the joining technology of parts which create strong driving forces for further advancements in this field. Even though a constructor has a considerable assortment of these components, there is still a noticeable demand for additional types of screws, bolts, and nuts [5]. The evolution of applications and technologies created an increase in the demands of the quality of bolted joints; this also applies to the materials, production technologies, specific geometries, surface finishes, a variety of coatings, and lubricants [6–8].

The Fredonia Group has good predictions for the fastener market on a global scale till the year 2018. Some pieces of the report presented in Ref. [9] illustrates the immodest industrial fastener market will grow with an annual average of 5.4% till the 2018 forecasted period of $93.8 billion. According to the forecastes, the market for fasteners will be supported by the increase in the production of motorvehicles, machinery, and other durable goods. an increase by 2018 will concern both developed and developing countries. It is, therefore, From an economic point of view, investments in this area should ensure a good return on capital, and it is worthy of consideration.

Additionally, in the latest studies focused on the advancement of nuts and bolts, it is evident that the economic key issues are threaded fasteners quality, and the lack of competitive equilibrium due to the absence of multi-parametric quality control of the assembly and the friction behavior dispersion [10–12]. The functional characteristics of threaded fasteners are affected by different aspects, which include the production materials, the shape and thread pitch of bolts and nuts, the bolts and nuts manufacturing processes, the heat treatment process and the associated parameters, and the application of additional protective coatings to the fasteners [13]. Complementary to these factors, which are functional, are factors relating to assembly, such as the design of the assembly, the hole clearance, the torque and clamping force applied, the tightening speed, the number of tightening and loosening cycles, and the use or absence of lubrication. Some of these factors have significant influence, while others have only a minor importance on the effectiveness of the assembly.

In a bolted joint, the most critical aspect that affects the joint's reliability and longevity is the clamping force. This is related to factors such as torque and the coefficient of friction [14]. Research paper [15] addresses the structure of parameters pertaining to the tightening of a fastener, and positions the friction coefficient value under a bolt head as the most critical factor affecting bolt tension. The goal is to manage these parameters and their variation to ensure that the joint is assembled correctly [16]. This is especially critical in applications where safety is a major concern such as in the aeronautics and automotive industries. In the USA, studies conducted on automotive service managers found that, of all service related issues, 23% of them were due to loose fasteners [17]. Additionally, they discovered that new vehicles also had loose fasteners in 12% of the cases. Similar issues related to fasteners exist in many other sectors. The primary cause of loosening fasteners is inadequate tightening. A single bolt that is poorly tightened can result in the complete failure of a product [18, 19]. As a result, there is a growing demand for fasteners to meet high quality standards.Modern highly automated assembly processes place great importance on the presence of non-defective bolts and nuts. This means the components need to be suitable for assembly robotics in order to allow an uninterrupted and seamless assembly flow.

The study presents and discusses that one of the major issues in threaded connections is the real measurement of precise performances and the accurate predictions of the case of clamping force when the measuring torque is being controlled. There is significant scientific research and tribological studies, yet there is still insufficient knowledge of the real contact area of the tightening surfaces [20, 21]. The problem is worsened by the fact that there are two competing, divergent manufacturing processes of the threaded surfaces, which is either by cutting or by plastic deformation. The fundamentals of the manufacturing process for screw production have been described over 100 years ago. The first bolt production was automated and it yielded a production rate of about 70 bolts a minute. In general, industrial metallic screws are made of low to medium carbon steel wire although other alloys are used depending on the end application in consideration of the performance/cost balance. Currently, stainless steel, brass, nickel, or aluminum alloys are also used. The processed surfaced and the roughness of the machined surfaces is not the same as the frictional process [22, 23]. Tightening friction process of bolted connections has varied frictional sources as one can find.

In the worst case, the worst case scenario aligns with the formation of scuffing of the friction pair [24–27]. Mere surface contact with surfaces can lead to scuffing and catastrophic adhesive wear, and the worst case scenario would lead to the worst case contact scenario adhesive wear, and the worst case contact scenario scuffing naure of contact with surfaces]. Scuffing can be described as the adhesive wear of friction pairs as a result of surface interfaces coming into contact at a magnitude that exceeds the plastic deformation of the material and the heat generated from fusion of the material surfaces in the micro contact areas of the surface interfacial fusion and adhesion, mechanical interlocking, and micro structural adhesion. Scuffing is a defect characterized by micro scuffing in the contact friction pairs. The micro structural adhesion of surfaces leads to the fusion of material surfaces and the micro friction of surfaces leads to the micro deformation and surface micro) fusion of surfaces. The mic contact of surfaces leads to micro adhesion of surfaces which leads to micro and macro fusion, micro deformation and surface micro friction, micro adhesion of surfaces and macro friction inter surfaces of the surfaces themselves. Scuffing can be described as the adhesive wear of friction pairs as a result of surface interfaces coming into contact at a magnitude that exceeds the plastic deformation of the material and the heat generated from fusion of the material surfaces in the micro contact areas of the surface interfacial fusion and adhesion, mechanical interlocking, and micro structural adhesion. Scuffing is a defect characterized by micro scuffing in the contact friction pairs. The micro structural adhesion of surfaces leads to the fusion of material surfaces and the micro friction of surfaces leads to the micro deformation and surface micro) fusion of surfaces. The mic contact of surfaces leads to micro adhesion of surfaces which leads to micro and macro fusion, micro deformation and surface micro friction, micro adhesion of surfaces and macro friction inter surfaces of the surfaces themselves. Scuffing can be described as the adhesive wear of friction pairs as a result of surface interfaces coming into contact at a magnitude that exceeds the plastic deformation of the material and the heat generated from fusion of the material surfaces in the micro contact areas of the surface interfacial fusion and adhesion, mechanical interlocking, and micro structural adhesion. Scuffing is a defect characterized by micro scuffing in the contact friction pairs. The micro structural adhesion of surfaces leads to the fusion of material surfaces and the micro friction of surfaces leads to the micro deformation and surface micro) fusion of surfaces. The mic contact of surfaces leads to micro adhesion of surfaces which leads to micro and macro fusion, micro deformation and surface micro friction, micro adhesion of surfaces and macro friction inter surfaces of the surfaces themselves. Scuffing can be described as the adhesive wear of friction pairs as a result of surface interfaces coming into contact at a magnitude that exceeds the plastic deformation of the material and the heat generated from fusion of the material surfaces in the micro contact areas of the surface interfacial fusion and adhesion, mechanical interlocking, and micro structural adhesion. Scuffing is a defect characterized by micro scuffing in the contact friction pairs. The micro structural adhesion of surfaces leads to the fusion of material surfaces and the micro friction of surfaces leads to the micro deformation and surface micro) fusion of surfaces. The mic contact of surfaces leads to micro adhesion of surfaces which leads to micro and macro fusion, micro deformation and surface micro friction, micro adhesion of surfaces and macro friction inter surfaces of the surfaces themselves.

An example of microcracks appearing in threads of nuts may be attributed to loss of clearance in nut-and-bolt threaded connections due to the incorrect threaded geometry of the nut. During the tightening process, the material used to manufacture the bolts may influence the process. For example, for bolts made of austenitic materials, while the torque applied may be the same, the preload may be lower from a scuffing standpoint as bolts made of austenitic materials are more prone to scuffing. This is in relation to the materials neutral viscous type behavior, which in turn, leads to a higher incidence of cold welding than is normally found in bolts of a lower grade steel. The type of surface finish treatment can significantly influence the operational behavior of the screw threads. For example, Electro-Zinc Plated (EZP) finish can modulate the total torque required to mount the screw to be higher and can also increase friction when compared to other finishes. This type of coating can also lead to a large batch to batch variation in this regard. In this regard, the Zinc Flake Finish (ZFF) is often suggested as a substitute for EZP. Sealer with integrated lubricant applied to the EZP can lower the friction coefficient to appreciably less than one and can reduce the scatter in the torque-tension relationship significantly.

Even though there are no additional lubricants to stabilize the friction coefficient, primary galvanic coatings are still common in the automotive threaded fastening industry. Most manufacturers design their bolted joints according to the VDI 2230 Part 1 guide [29]. This guide categorizes the coefficient of friction, aiming to achieve class B, which has a coefficient of friction of 0.08–0.16. This is achievable with the inclusion of friction modifiers (graphite, $MoS_2$, PTFE).

Achieving a specific torque when fastening a threaded component is considered the most conventional and accepted method in the industry for tightening fasteners. It is, however, not the most accurate, as the same torque can produce a wide range of variations in preload (the axial force resulting from a tightening operation). For example, the required mounting torque can be achieved without the corresponding axial clamping force as intended.

"Scientist" in this sense means the ability to utilize multi-scale metrology in the measurement of a dimension, in addition to the ability to decipher the tribological signature of a manufactured surface. A fundamental problem, arguably the biggest problem, with the method of torque control, which most people will tell you directly deals with clamping force in a fastener, is that a very tiny portion of the torque that is applied to a fastener actually contributes to the stretching of the bolt. Almost all of the torque is ‘used up’, or ‘spent’, in the friction between the nut face and the joint, and in the threads. Although the phenomena involved in the tightening process and the contact surfaces remain a primary focus… there is still a remarkable lack of knowledge concerning the fundamental phenomena involved in the formation and evolution of the contact area.

**Experimental Procedure of Tightening Process**

M10x60 bolts from property class 8.8 (30MnB4 steel, cold forged and thread rolled as in [33], with a coating of electrolytic zinc < 8μm) were used in the empirical study.

This technique provides the opportunity to realize the benefits of the mechanical characteristics of the fasteners and simultaneously realize savings in the amount of material used. The specific stages of the forming of the bolt by means of plastic deformations are illustrated in the picture. The last image depicts the bolt after the thread rolling operation. The thread is created through the plastic deformation of the shank, with no material being removed from the shank.

The steel used for the analysis is 30MnB4 (EN 10263-4) [34].

Manufacturing a bolt involves several stages. These include material preparation, cold, warm, or hot forming, and thread rolling. A cycle for material preparation often includes the following: the annealing of steel coils (called spheroidizing), cold drawing, and before and after forming, the steel coils undergo HCL (hydrochloric acid) pickling and phosphating. The bolts are typically produced in multiple-station forming machines, which perform cutting, heading, extrusion of the material, and thread rolling. The time taken to perform the functions in the forming machine is very short and for a multiple station machine, it takes about a minute to produce, depending on the complexity and the dimensions of the fasteners, anywhere between 300 fasteners. There are several processes that take place during the cooling cycle in the forming machine, these include heat treatment to give the fastener the required mechanical properties, lubricating the fasteners to attain the desired coefficient of friction, and applying a coating for corrosion resistance and to control the level of corrosion on the fasteners.

For this experiment, the manufacturing process line picked nuts and bolts at random. Selected bolts were made as per DIN 933 for threaded fasteners. It should be noted that although the DIN 933 for fasteners is widely accepted, it is being supplanted by the ISO 4017 standard [35]. Selected items were dimensionally filtered prior to each tribological test. This means that only bolts and nuts that were adequately prepared were allowed to proceed; the rest were rejected. Twenty pieces nuts and bolts of each of the two types were chosen.

The mean hardness of the frictional components of the bolts heads, M10x60, was 324 HV, under a 300 g load.

The systematic tribological investigations were conducted with the selected samples on the standardized devices (ISO 16047 [36]) for threaded fasteners, which provide the possibility to measure total torque in the range of 0-200 Nm, clamping force in the range of 0-100 kN, and thread torque from 0 to 150 Nm.

**System Overview**

This concerns a new washer used to affix the rear driveshaft flange using M10 bolts.

It works with the existing assembly configuration, which includes:

- Driveshaft flange and CVJ (Constant Velocity Joint) parts
- M10 fasteners
- Single and dual spindle torque tools
- Automated tightening systems and controllers.

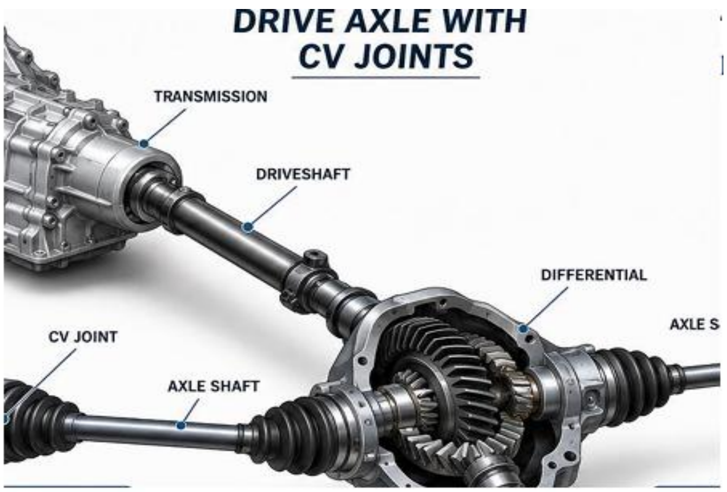


***Fig. 1.*** *Single Propeller Shaft CVJ Assembly Details*

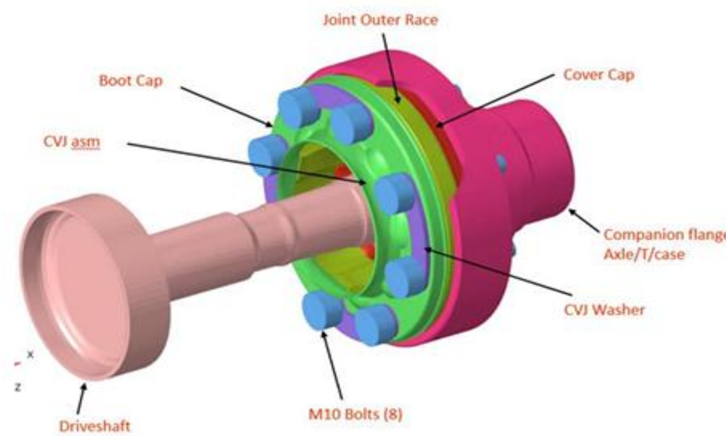


***Fig. 2.*** *Driveshaft CVJ*

**Key Components and Modifications**

The design modifications encompass three primary adjustments pertaining to the washer:

1. Increased hole diameter. Modification made from 10.5 ± 0.3 mm to 10.72mm upto 10.69mm. This allows for greater clearance to avoid interference when inserting and securing the bolt.
2. Improved tolerances on hole location and size. This guarantees superior manufacturing quality and compliance with the tolerances.
3. Applied Zn/Al coating. This decreases washer thickness by 10–15 microns and results in reduced surface friction and smoothness during assembly.

**Problem Statement**

At the time of production, the following issues were identified:

- Washer binding primarily occurred in the eighth iteration of the tightening cycle.
- Operators frequently needed to pause the cycle to stop and re-tighten the bolts, resulting in delays to the cycle.
- Dual spindle tools experienced a greater number of binding incidents.
- The threads on the bolts and the housing were damaged as a result of repeated binding.
- There was an increase in cycle times and downtime of the machines due to frequent stoppages.
- More manual work meant increased safety risks.

These issues required a dependable, economical, and easy-to-use solution.

Washer is struck during the assembly operation

**Proposed Solution**

The new washer design addresses the root cause of binding by:

- Increasing the hole size for more clearance

- Using tighter tolerances to prevent misalignment
- Applying Zn/Al coating for less thickness and friction

This redesign ensures:

- Easier bolt insertion
- No interference between the washer and the bolt
- Better tool stability and torque application
- Less need for operator involvement.

| CONCLUSION | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Sr.No | Stack No | DESCRIPTION | Worst Case | | RSS | | | |
| | | | Max | Min | Max | Min | % YIELD | DPMU |
| 1 | 1 | Bolt Clearance @ Plate hole size is 10.5 | 1.100 | -0.100 | 0.800 | 0.200 | 100% | 2.000 |
| What if | | | | | | | | |
| 2 | 2 | Bolt Clearance @ Plate hole size is 10.625 | 1.225 | 0.025 | 0.925 | 0.325 | 100% | 0.000 |

*Bolt Clearance VSA study*

| # | Dim # | Component Name | Part No. | Rev. | Description | Loop | Vect Dir. | Mean | Tol. ± | $C_p$ | Mean with Direction | Tol. ± | Tol. Squared | RSS Contribution % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | P9 | Rear Prop Shaft | 0 | 0 | Clearance Hole Radius | A | 1 | 5.313 | 0.150 | 1.000 | 5.313 | 0.150 | 0.023 | 25.00% |
| 2 | P2 | Cover Plate | 0 | 0 | Distance between two holes | B | -1 | 37.000 | 0.200 | 1.000 | -37.000 | 0.200 | 0.040 | 44.44% |
| 3 | P9 | Rear Prop Shaft | 0 | 0 | Clearance Hole Radius | C | 1 | 5.313 | 0.150 | 1.000 | 5.313 | 0.150 | 0.023 | 25.00% |
| 4 | P4 | Rear Axel | 0 | 0 | Bolt Radius | D | -1 | 5.000 | 0.000 | 1.000 | -5.000 | 0.000 | 0.000 | 0.00% |
| 5 | P3 | Rear Axel | 0 | 0 | Positional tol of Threaded hole | | 1 | 0.000 | 0.050 | 1.000 | 0.000 | 0.050 | 0.003 | 2.78% |
| 6 | P5 | Rear Axel | 0 | 0 | Distance between Threaded Holes | E | 1 | 37.000 | 0.000 | 1.000 | 37.000 | 0.000 | 0.000 | 0.00% |
| 7 | P3 | Rear Axel | 0 | 0 | Positional tol of Threaded hole | | 1 | 0.000 | 0.050 | 1.000 | 0.000 | 0.050 | 0.003 | 2.78% |
| 8 | P4 | Rear Axel | 0 | 0 | Bolt Radius | F | -1 | 5.000 | 0.000 | 1.000 | -5.000 | 0.000 | 0.000 | 0.00% |
| | | | | | | | | | | | 0.625 | 0.600 | 0.090 | 100% |

| LOOP EQUATION |
|---|
| X=A-B+C-D+E-F |


| Result Summary | | | |
|---|---|---|---|
| Worst Case | | | |
| Mean | Tol. ± | Max | Min |
| 0.625 | 0.600 | 1.225 | 0.025 |
| RSS | | | |
| Mean | Tol. ± | Max | Min |
| 0.625 | 0.300 | 0.925 | 0.325 |

| | |
|---|---|
| Mean: | 0.625 |

*Clamp Load Study*

| Interface | Clamp Load | Torque at 95% shear capacity | |
|---|---|---|---|
| | | Target | Calculated |
| Cover Cap –Flange (Interface 5) | 31.9 kN | > 1872 Nm | 2802 Nm |
| Under Head Bolt (Interface 1) | | > 2765 Nm | > 4710 Nm |

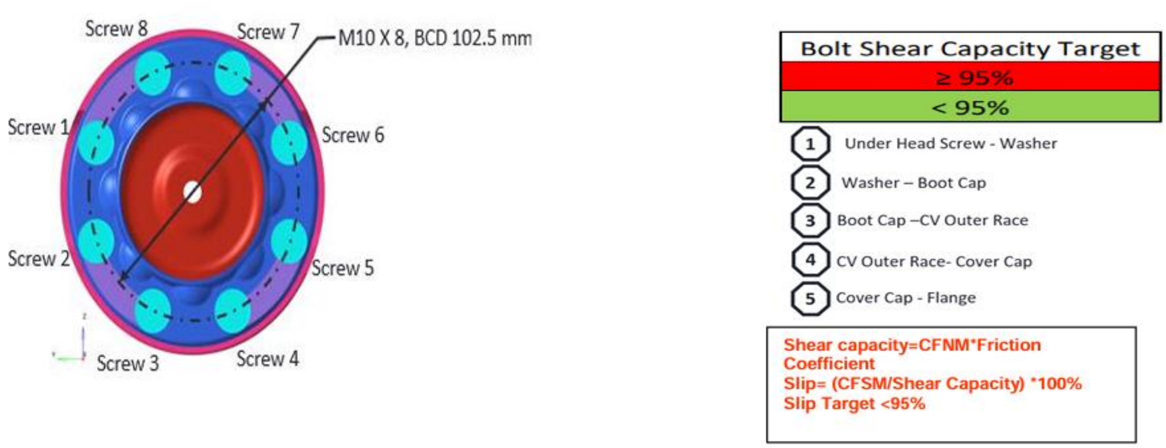


***Fig. 3.*** *Bolt Shear Capacity and Interface Slip Assessment for the Rear Driveshaft Flange Assembly*

**How the Invention Solves the Problem**

The redesigned washer increases easy assembly and eliminates binding in the following ways.

- Designed to prevent binding
- Has dual singles and dual spindles
- Overall cycle times improve. No rework. No stoppages.
- No tightening sequence means more flexibility.
- Less operator contact with moving parts increases safety.
- Integrated into current production method with no added costs.
- Ensures CVJ parts remain secured in assembly process
- Defeated all tests for bolts slipping and torque failure. Mechanical strength was confirmed.

**Results and Validation**

Testing demonstrated that the upgraded washer:

- During multiple testing cycles, there were no reports of binding
- Integrated with the current torque tools
- Cycle time was reduced
- No thread damage or deformation of the washer was observed
- Assisted tightening, meaning no manual intervention was required

**Conclusion**

The washer design successfully addresses the issue of washer binding when assembling rear driveshaft flanges. Improvements to the design have resulted in easier assembly, a reduction in machine downtime, improved safety, and no additional cost due to the design improvements. The redesign has been tested and approved for full-scale production. Considering the various elements of the production system and how the tribological interface of the fastener varies in the course of the production system and the specific focus of the experimental research, the following conclusions can be drawn.

The tribological interface in a bolted assembly results in the torque required to achieve a specific preload on a nut and bolt assembly to be highly variable. In any sector of the economy where the tightening of fasteners is performed by a machine, there is a requirement for control of the assembly torque to be within a certain, and in the case of a research, a narrower range than that which has been reported.

The coefficient of friction measured from the bearing torque is, on average, 44% higher than that measured from the thread torque. The tightening process complexity leads to poor predictability of total torque as the clamping force increases. The tightening process total torque evolution is parabolic, contrary to the standards which expect a linear relationship.

During tightening processes, the real contacts that form at the interacting surfaces are difficult to predict as they are a function of the surfaces' macro-geometries and micro-morphologies.

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