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DESIGN OF A STEERING COLUMN FOR A COMMERCIAL VEHICLE

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ABSTRACT

Design, development, test and validation process of a steering column with telescopic and tilt adjustment is mentioned in this study which is funded by Tubitak. The steering column is designed with the purpose of assembling it in M3 class commercial vehicle. In order to increase market share of this commercial vehicle that has only telescopic steering column, tilt adjustment capability is implemented to the steering column. Moreover works on weight reduction, cost reduction; solution of product quality problems of steering column are explained in this article.

Keywords: Steering Column, Telescopic, Tilt, Non-uniformity, Adjustable Steering System, Irregularity

BİR TİCARİ ARAÇ İÇİN DİREKSİYON KOLONU TASARIMI

ÖZET

Tubitak tarafından desteklenen bu çalışmada, M3 sınıfı ticari bir araçta kullanılmak üzere açısal ve doğrusal ayarlama özelliklerine sahip direksiyon kolonu tasarımından ve geliştirme faaliyetlerinden bahsedilmektedir. Bu özelliklere sahip direksiyon kolonunun adapte edileceği araç üzerinde sadece doğrusal harekete sahip direksiyon kolonu bulunmaktadır. Pazardaki rekabet edilebilirliği artırmak amacıyla doğrusal öteleme hareketinin yanı sıra direksiyon kolonuna açısal olarak da hareket edebilme kabiliyeti eklenmiştir. Aynı zamanda ağırlık azaltma, parça maliyeti azaltma ve daha önceki tasarımda rastlanan müşteriyi doğrudan etkileyecek ürün kalite problemlerinin ve fonksiyonelliğin iyileştirme konuları ele alınmıştır.

Anahtar kelimeler: Direksiyon Kolonu, Teleskobik, Tilt, Düzgünsüzlük, Ayarlanabilir Direksiyon Sistemi

1. INTRODUCTION

Steering column is a linkage part operating between steering wheel and steering gear. Main function of the steering column is to transmit steering force and steering torque input from steering wheel to steering gear. Steering column assembly also includes anti-theft locking device, ignition key, wiper and signal switches and sensors and electrical harness of these devices, trim covers and steering angle sensor. In addition, column-PAS (power assisted steering) system provides necessary assisting torque from electric motors and gears system on it, this system can be integrated to ESP with steering angle sensor. By this way, steering gear can be used as only linkage part.

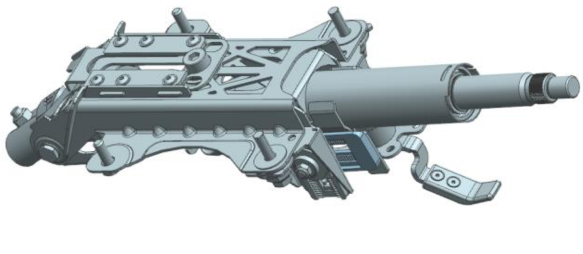

Figure 1. Steering Column

Steering columns are categorized in two groups according to adjustment capability. One of them is non-adjusted steering column. Non-adjusted steering columns are used in heavy duty machines, tractors, or military vehicles. There is a fixed shaft between steering column and steering mechanism in this type of steering columns.

Other type of steering column is adjustable. Passenger can adjust the steering wheel position in axial and angular directions in order to obtain better driving position. These types of steering columns are used in passenger cars and commercial vehicles such as light duty vehicles, buses and trucks. M3 Class vehicles usually have telescopic and tilt steering columns.

2. THEORETICAL DESIGN

The steering linkage system includes universal joints or double joints, steering column, intermediate steering shaft, locking mechanism and jacket tube. The steering linkage connects the steering wheel to the steering gear by means of the mechanically components. This linkage system enables to transmit steering force and steering torque input from steering wheel to steering gear.

Universal joints consist of two forklike yokes and across-shaped center component which connects the two yokes. The center cross features four sealed needle bearings which allow it to swivel about each of its axes. The cross is a case-hardened component with machined bearing seats. Universal joints allow the path of the steering driveline to contain multiple angles. When rotating, an angled universal joint generates sinusoidal irregularities (sometimes called as non-uniformity) in the steering angle and torque transmission.

Figure 2. Universal Joint

Multiple connected universal joints (also called double joint) can be oriented such that these irregularities compensate for one another. If the universal joints of double joint are positioned appropriately and symmetrically with respect to the neutral steering position, steering irregularities can be eliminated. If irregularities of steering linkage can't be eliminated, constant velocity joints (also called CV joints) can be used to eliminate it.

The lower part of the steering column consists of an intermediate steering shaft routed from passenger compartment into the engine compartment. A seal part is used on the steering shaft to prevent wind, water, and noise from entering the passenger compartment without causing additional friction. The steering shaft seal is generally double-walled and often made from high temperature materials.

Figure 3. Intermediate Steering Shaft

Telescoping systems enable the steering wheel to be adjusted axially while tilt systems enable the steering wheel to be adjusted in angular direction. For applications where operating temperatures and steering torques are within an acceptable range, telescoping and tilt systems are designed using polygonal shaft and tube profiles with plastic coatings or bushings. Whereas telescoping and tilt adjustment systems must be operable with forces between 0 and approximately 80 N.

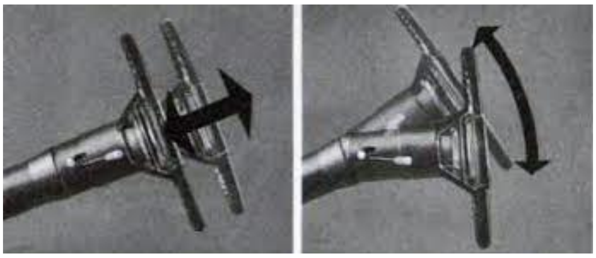

Figure 4. Telescopic and Tilt Adjustment

For applications with higher operating temperature or torque requirements, all-steel systems such as complex linear ball bearings are used. Ball bearings are very important with regards to torque to rotate of steering shaft. These components should have low inner friction in order to decrease torque to rotate of steering shaft. Otherwise, ball bearings restrain the steering shaft turning ability and in that case steering shaft can't easily be rotated. This problem can badly affects steering effort on steering wheel. Moreover, quantity of bearings can be two or three in steering column. These bearings should be aligned in same axis in order to prevent misalignment problem, this also badly affects torque to rotate of system and it creates additional steering effort on steering wheel.

The upper portion of the steering column is mounted on ball bearings and contained within a jacket tube to enable the adjustment of the steering wheel. The jacket tube contains the steering column locking mechanism. In addition, the control unit and the interior trim panels are mounted to the jacket tube. Any electromechanical actuators to vary torque or steering angle are also mounted to the jacket tube. The wiring harness for the control unit is also mounted to the jacket tube.
The classic mechanical steering lock is located directly behind the steering wheel. It is used as anti-theft device.

When the lock is engaged, a latch mechanism slides a pin into a locking sleeve on the steering shaft, thus prohibiting the rotation of the steering linkage.

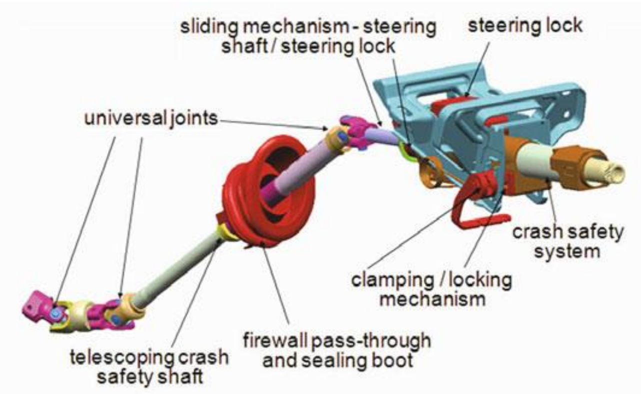

Figure 5. General View of Steering Column

3. PRODUCT DEVELOPMENT

Functionality of steering column is aimed to improve in product development phase. Development related issues are shown in below:

1) Telescopic adjustment effort (force) of steering column is decreased.
2) Strength of locking mechanism that used in telescopic adjustment is increased.
3) Weight reduction of steering column is acquired.
4) Cost reduction in some sub-components of steering column is applied. Some cost reduction workshops are executed during design and development process.

Firstly, some benchmark workshops are performed in order to decide which design is better for telescopic and tilt adjustment. According to these workshops, it can be said that two direction adjustments can be applied with the help of new design of steering column brackets or new design of steering column body with new slots. Angular motion (tilt) is created with a secondary centering bolt and a sliding bracket that slides on a fixed bracket. Angular motion is a rotation motion around the axis of this bolt.

Design of clamp lever and locking mechanism is very important in terms of design of steering column. Design of locking mechanism and sliding bracket are crucial to prevent any motion (including sliding of column and vibration at idle condition etc.) of steering column at any position when the locking mechanism is locked on. There are two types of locking mechanism. One of them is manual clamp lever mechanism, the other is spring type clamp lever mechanism. Manual clamp lever mechanism depends on tightening capability of driver. Clamp lever in manual type connects two sliding parts together with a bolt and jam nut. While clamp lever is turning, bolt goes into and it compress the sliding bracket upon fixed bracket. Manual type is a cheap solution, it is more simple than other design solution. However, it causes some quality problems because tightening force and performance in that design depends on driver. Main problem of this design is shaking of steering column because of insufficient tightning force of clamp lever although the locking mechanism is locked on. Also tightened clamp lever position is variable by reason of variable tightning force applied by driver.

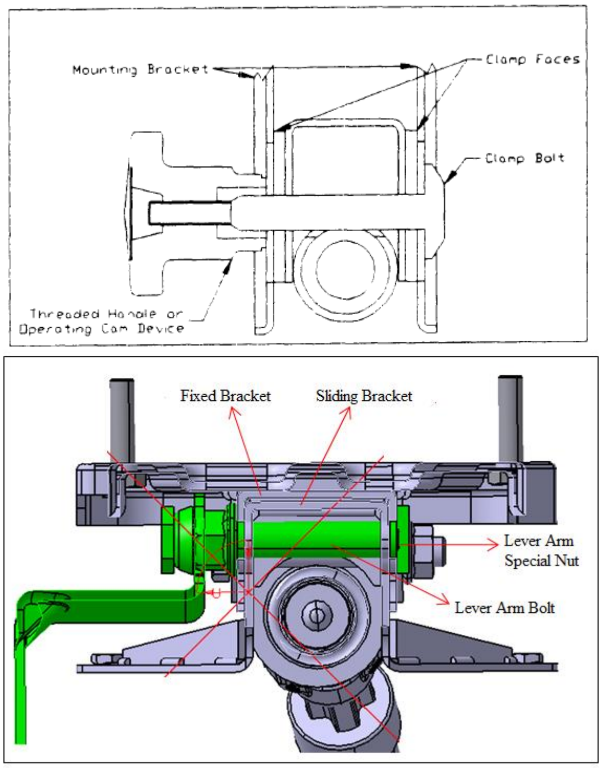

Figure 6. Manual Type Clamp Lever Mechanism

On the other hand, tightened clamp lever position is not variable and it doesn't relate with force applied by driver in spring type clamp lever mechanism. In this type, tightened and un-tightened clamp lever positions are specified as design criteria with the calculation of spring stiffness. The clamp lever mechanisms of Mercedes E and C Class passenger cars are examined as a benchmark research. Ball bearing is attached to clamp lever so this part provides springing while tightening is necessary. Clamp lever moves on ball bearing and in an angle tightening is occurred.

Springing effect on steering column is provided by plates shown in **Figure 7**. With the usage of these plates on locking mechanism tightening of clamp lever can be independent from driver force applied to lever and driver has more accurate tightening feeling while using the locking mechanism. No matter how this locking mechanism is the best design solution, it is an expensive one and this is the disadvantage of this mechanism.

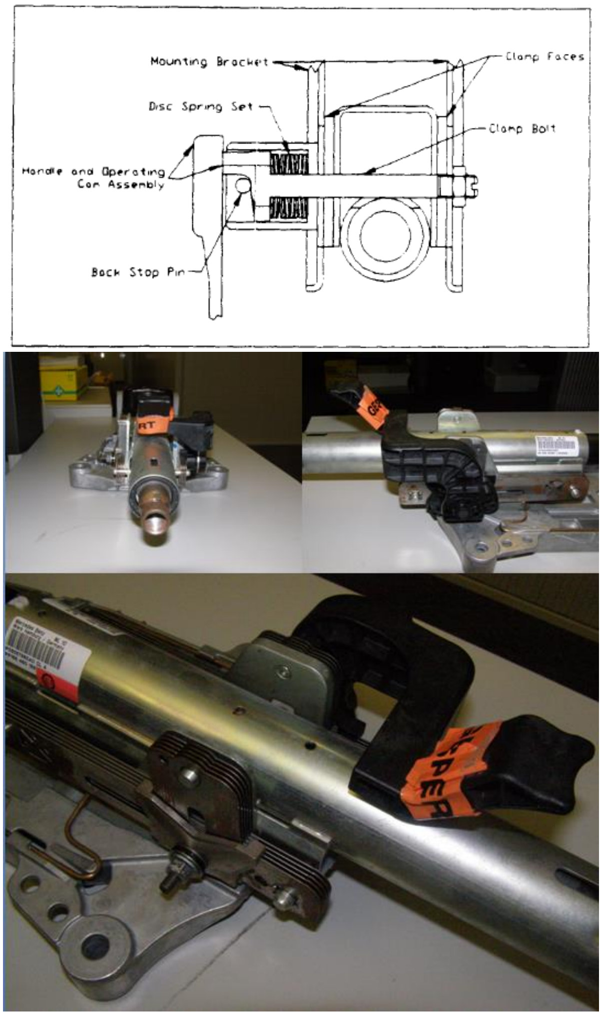

Figure 7. Spring Type Clamp Lever Mechanism

Development of steering column was performed by evaluating these advantages and disadvantages explained above. Combination of first and second solution was applied in design process to make the design best. Steering column should have lower cost and higher performance on behalf of locking mechanism. Tightening of clamp lever should be independent from driver force applied to lever and driver should have more accurate tightening feeling while using the locking mechanism. It is aimed on design of mechanism that sliding of parts on each other is necessary to obtain tightening with geometrical contact. In addition, both telescopic and tilt adjusting can be provided on clamp lever, it is important in terms of locking parts design. To provide all these design necessities, a fixed bracket, a sliding bracket, a clamping lever, locking parts and special nut & bolt are used in locking mechanism.

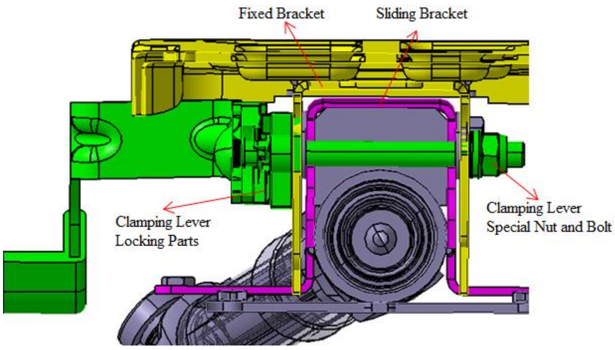

Figure 8. Steering Column Locking Mechanism

Ergonomics analysis was performed in order to specify telescopic and tilt adjustment displacement. According to this analysis, necessary angular displacement of center point of steering wheel should be 40 mm while axial displacement of it should be minimum 45 mm. In order to achieve ergonomics targets, total tilt angle and axial displacement of steering column should be decided. As mentioned in ‘Theoretical Design’ part, non-uniformity is crucial in steering system geometry and kinematics. Change in tilt angle affects the angle of upper universal joint and it causes change in non-uniformity. In order to keep non-uniformity minimum, the centering bolt that provides angular adjustment is positioned as close as possible to the axis of universal joint (shown in **Figure 9**). The non-uniformity of steering kinematics is decreased by reducing the change of joint angle with this way. To achieve ergonomics and steering system kinematics targets, tilt angle and total telescopic displacement were decided as 7° and 50mm. (shown in **Figure 10**)

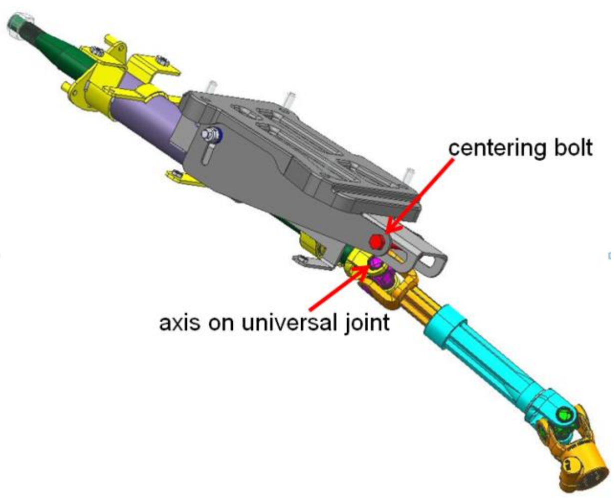

Figure 9. Location of centering bolt and joint

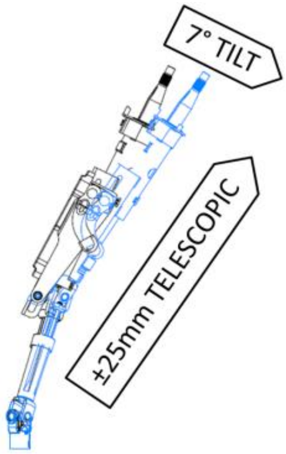

Figure 10. Axial and Angular Displacement

The angular velocity at point D (pinion rotation) is related to the angular velocity at point A (steering wheel). According to the parameters mentioned below, the non-uniformity can be calculated. For all tilt and telescopic adjustment positions total peak to peak angular velocity difference must be a range in the vehicle program target.

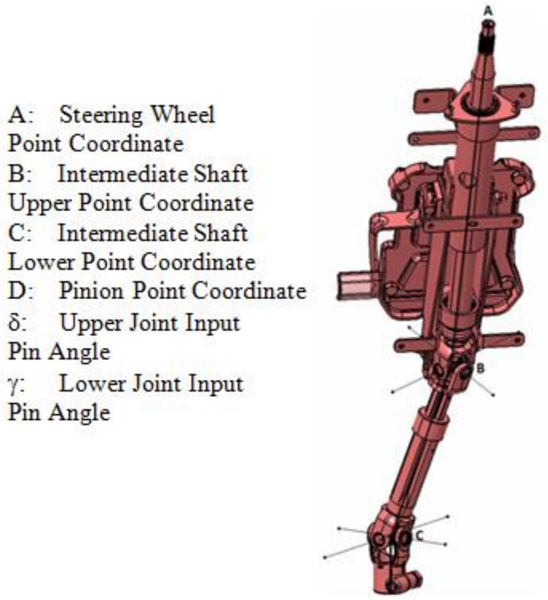

Figure 11. Steering Non-Uniformity Hardpoints

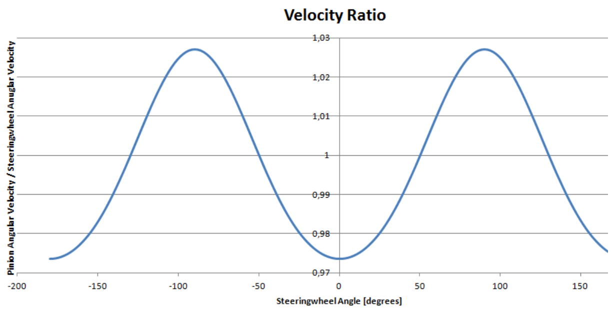

Figure 12. An example of the non-uniformity chart

4. TEST & VALIDATION

Test & Validation process includes bench tests, manufacturing process of final level prototypes including sub-components of the product. Bench tests are performed in order to acquire the final product that has no error or error state. Classification of bench tests is shown in **Figure 13**.

Figure 13. Steering Column Test Bench Room

Test bench software is used to get data from bench tests. Cycle bench tests such as Tilt & Telescope Operation Durability and Egress – Ingress Test especially had been improved with some sensors, some pistons and servo motors. After this improvement, tuning process of these cycle tests had begun in order to get the best results from benches. This tuning process includes:

- Location tuning of stoppers
- Location and force tuning of pistons and servo motors
- Adjustment of stabilizers to test bench
- Sensor adjustments to necessary locations
- Providing communication between test benches and software in order to get test data

In addition, software development process had been held for Tilt & Telescope Operation Durability Bench Test. At the end of these workshops on software, important parameters that listed had been controllable transiently by the screen.

- Cycle number
- Phase number
- Time of force applied to steering column
- Instant and maximum locking mechanism lever force
- Instant and maximum steering column vertical force in design condition
- Instant and maximum steering column vertical force in tilt condition
- Instant sliding force of steering column when locking mechanism off

Figure 14. General view of Bench Test Software

4.1 Tilt & Telescope Operation Durability Test

Test had been performed and each cycle has 10 phases explained in below:

• 1st phase: Measuring of force of lever in design position during locking operation.

• 2nd phase: Applying vertical force to steering column in design position, when locking mechanism on. (Steering column should not slip in telescopic direction with the force applied, any slippage is caused to stop test)

• 3rd phase: Measuring of force of lever in design position during un-locking operation.

• 4th phase: Measuring of sliding force in telescopic direction in design position, when locking mechanism off.

• 5th phase: After passing to tilt position, Applying vertical force from below to tilt part of steering column in tilt position, when locking mechanism on. (Steering column should not slip in tilt direction with the force applied, any slippage is caused to stop test)

• 6th phase: Measuring of sliding force in telescopic direction in tilt position, when locking mechanism off.

• 7th phase: Measuring of force of lever in tilt position during locking operation.

• 8th phase: Applying vertical force to steering column in tilt position, when locking mechanism on. (Steering column should not slip in telescopic direction with the force applied, any slippage is caused to stop test)

• 9th phase: Measuring of force of lever in tilt position during un-locking operation.

• 10th phase: Passing to design position this bench test has included the validation of tilt & telescope operation of steering column in the scope of;

• Slip force durability of steering column.

• Sliding force (that can be chosen according to the program target) of steering column in tilt & telescope operation when the locking mechanism off

• Force and effort (that can be chosen according to the program target) of locking mechanism lever.

• Locking mechanism parts durability (erosion limit for functionality, visual check)

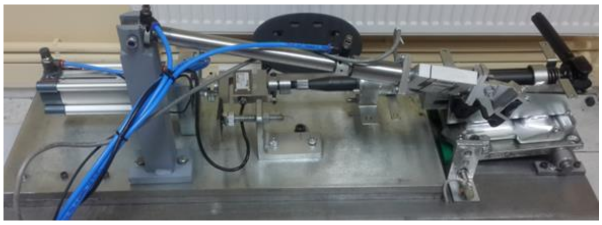

Figure 15. Tilt & Telescope Operation Durability

4.2 Egress Ingress Test

Test is performed from 3 directions: right side, left side and bottom side of steering wheel. Steering wheel is pulled from these three sides with the target force. For left and right sides pull force is applied to steering wheel while from bottom side pull and push force are applied separately.

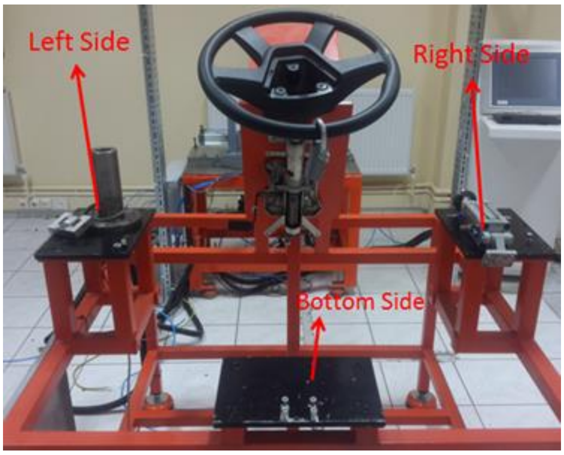

Figure 16. Egress Ingress Test Bench

After the test, visual checks are performed in order to determine damages on steering column sub components. In addition during bottom side pull and push test, the steering column should not be slipped and this slippage is controlled by a displacement sensor.

Figure 17. Egress Ingress Push and Pull Position

4.3 Rotating Looseness Test

This test bench is used to measure looseness of torque transmission components like steering slippage shaft mechanism, total backlash of joints and other parts as bearings. Total backlash value of the steering column would be less than program target value.

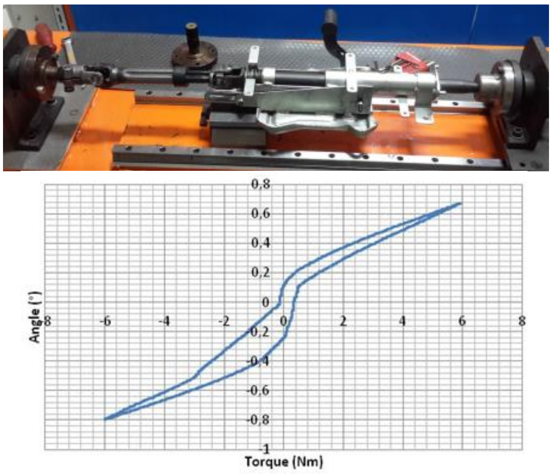

Figure 18. Rotating Looseness Test Bench

4.4 Torsional Breaking Strength Test

This test bench is used to check strength of the torque carrying components against both steering shaft and steering slippage shaft mechanism against requirements. Torque carrying components are tested at 0 ° joint angle until breakage happened. Minimum UTS (ultimate tensile strength) should be 245 Nm.

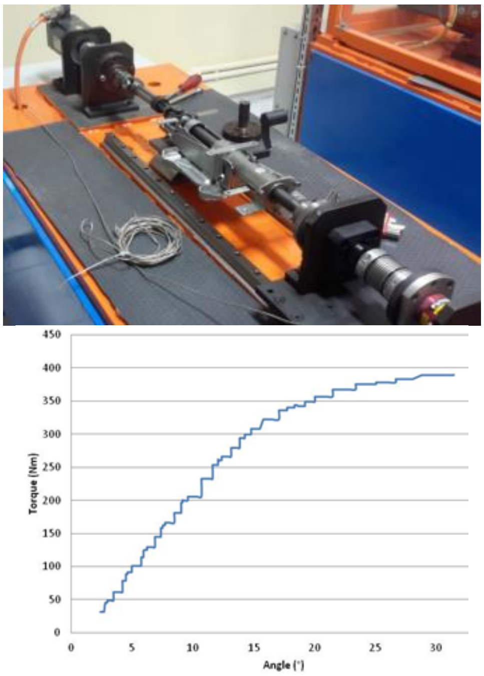

Figure 19. Torsional Breaking Strength Test

4.5. Torque to Rotate Test

This bench test is used to measure the torque value to turn the steering column when lower joint is assembled on the steering box shaft and all joint and shaft angles is simulated as vehicle position with necessary part such as angle drives, double joints and etc. Steering column is turned at lower rpm to clockwise and counter-clockwise directions. Maximum torque to rotate value is chosen according to program target. Measure the torque to rotate value at positions listed in below:

- Steering column in design condition
- Steering column in highest tilt level (positive side) that means steering wheel at lower angle position
- Steering column in highest tilt level (negative side) that means steering wheel at upper angle position
- Steering column in highest tilt level (positive side) and lowermost telescopic level
- Steering column in highest tilt level (positive side) and uppermost telescopic level
- Steering column in highest tilt level (negative side) and lowermost telescopic level
- Steering column in highest tilt level (negative side) and uppermost telescopic level

4.6. Torsional Endurance Test with Mud Water

This test bench is used to check corrosion resistance of steering column components to mud water. Steering column is assembled at vehicle layout conditions. Abrasive solution has been applied during the test. After the test, parts listed below should be free from practical problems:

- Sliding parts (sleeve yoke, yoke shaft and tube sleeve) functionality
- Condition of grease of sliding parts
- Degradation of grease.
- U-Joints functionality lock condition.
- Steering shaft and the bearings functionality

Figure 20. Torque to Rotate & Torsional Endurance with Mud Water Test Bench

5. CONCLUSION

In this study; a steering column that has tilt and telescope movement capacity is developed according to customer requests and ECE regulations. All development steps that includes concept design, product design and ergonomics, engineering and development process, virtual product, prototype, test and validation, 3D and 2D release, production line and after sale support has performed. The designed steering column has advanced lower telescopic and tilt adjustment effort with satisfying the customer expectations and competitive cost and weight in the market.

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