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Investigation of residual torque loss & its correlation with the process parameters

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Abstract: The study analyses the deterioration in torque loss over the time & its impact which can lead to functional loss or, in severe cases, vehicle breakdown. Findings from this research establish empirical correlations between process parameters and residual torque, offering valuable insights to improve the durability and reliability of soft joints in automotive applications. This paper presents an experimental study analyzing the effect of process parameters on rubber hose and plastic spout joints' performance, commonly used in pressure applications such as vehicle intake systems. The investigation focuses on key parameters, including specified torque, material properties of the components, tightening tool RPM, joint grip length, and clamp grip length. A systematic problem-solving approach is employed to conduct a detailed root cause analysis, addressing failure modes, identifying underlying causes, and proposing reliable solutions to enhance soft joint reliability.

I. INTRODUCTION

Typically, out of the total applied torque 80- 90% is used to overcome the friction & remaining 10-20 % is used for pre-load/ clamping load. Further, residual torque is the amount of tension that remains in a joint after a threaded fastener has been tightened, indicating how securely the joint is fastened. Measuring residual torque helps in verifying that the correct torque was applied & effectively transmitted during torquing operation and can also detect missed/ loose fasteners or joint relaxation. Residual torque is measured by rotation of fastener by application of torque in the torquing direction resulting in small angular displacement (typically 2-5 degree). The amount of torque at which the angular displacement starts happening is considered as residual torque. Dial screwdrivers, dial wrenches, digital torque wrenches, and torque testers with rotary torque sensors can be used for residual torque measurement. Breakaway torque is the torque required to break the fastener loose in the loosening direction and is often higher than the residual torque. Residual torque measurements are used by most industries to assess the torque of a fastened joint.

It has been observed that once a joint tightened with a specified torque, the residual torque can decrease & reduce without any external influence or application. This phenomenon is known as self-loosening/torque loss. This study is related to residual torque of soft joint & the process/ product parameters affecting the residual torque of soft joints. To monitor the phenomenon of loosening of torque in Screwed Clamps, Bolts & fasteners, torque audit is carried out to check the effectiveness of clamping force of a tightened joint. Following are the methods followed –

1. On-torque/Crack On method: On-Torque method is performed by rotating the nut/bolt by a marginal angle typically ranging from 2 to 10 degrees in the direction of tightening/applying torque.

2. Off-torque method: Torque is measured by rotating the fastener in the opposite/Loosening direction & off torque value is measured.

3. Marked fastener method: Marked fastener method uses both principles of measuring torque combining loosening & Tightening, Fastener –Bolt/Nut is marked in Tightened condition & is intendedly untightened by an angle of 30 Degrees then again Torque is given to tighten the joint to its marked position.

In Each method listed above, torque value measured is used to assess a tightened Joint.

Residual Torque in tightened joints can also be affected by:

1) Changes in temperature of tightened system.
2) Material of Tightened joint
3) Type of joint

We are considering negligible impact of change in temperature of system & the material of tightened joint is plastic pipe & rubber hose which remains same throughout analysis. Further types of joints are described as follows-

Soft Joint: Connection/joint in which used material for mating parts is flexible material such as rubber, plastic to seal the connection or joint. Soft joints generally required lower torque values to avoid damaging the plastic/flexible interface. Thus, in soft joints over tightening can cause further issues such as damage to the mating plastic/Flexible parts.

Hard joint: While hard joint is a rigid connection such as metal to metal joints and such joints also require a specified high torque compared to soft joints to ensure a secure joint

Fig 1 – An example of Hose Clamps used for soft joints

II. LITERATURE REVIEW

W. Eccles (2004), "A new approach to the checking of the tightness of bolted connections", Jost Institute of Tribotechnology and Bolt Science Limited, Chorley, U.K Focuses that clamping force of a tightened joint/bolted connection determines the reliability or success of the joint in its application. The structural integrity of the joint is dependent on multiple factors while tightening a joint. Tightening of a joint requires a great deal of attention so that the required clamping force needs to be achieved. A Tightened joint is required to resist the external forces & stress condition to maintain the rigidity & maintain its reliability under the required application so the any movement can be controlled. Commonly a threaded joint/fastener is tightened by applying a specific amount of torque below the yield point of the fastener. A bolt's Integration with the other tightening component can be ensured with a good structural integrity by providing a minimum clamping force so the connection would resist self-loosening under the influence of repeated transverse displacement of the Joint.

Camillo, J., The Importance of Torque Auditing. Assembly, 2013. November 2013 has shown that has Torque audit plays a pivotal role in establishing effectiveness of a tightened joint in a threaded fastener application. It could be carried out depending on the application with a set frequency such as after few minutes or hours. Not only used for verification of applied torque it also validates the process of tightening, Product design, Material used to ensure a robust joint.

III. PROBLEM DEFINITION

In a given soft joint, which comprises of rubber hose mounted over plastic spout, rubber hose gets dislocated (back-out) due to looseness in clamp. It can be described in following 5W + 1H format.

What- Rubber hose backout from plastic spout.

When-During vehicle usage

Who-End User

Where- Across Geographical Location across PAN India

Which- Reported in passenger vehicle segment across Diesel Engine over 1.5 L Capacity

How Big- 200+ & Critical failure due to Failure nature being -Vehicle Break Down & going Off road.

IV. PROBLEM STATEMENT

A critical analysis of torque loss and the influence of process parameters on residual torque in a soft joint between a rubber hose and plastic spout, designed for high-pressure applications, with the aim of preventing vehicle breakdown failures caused by torque loss and hose pull-out

IV. OBJECTIVE

The study will focus on identifying and mitigating factors responsible for torque loss, clamp loosening, and hose pull-out, aiming to improve the durability and reliability of the joints.

V. METHODOLOGY

Methodology carried out from PDCA approach of Problem solving is used for analysis & is carried out from Data Collection/Analysis>Root Cause identification>Solution Identification > Solution Verification/validation>Solution Implementation>Monitoring results.

1. Data Collection
2. Root Cause Analysis
3. Solution Identification
4. Solution Implementation
5. Monitoring Results

5.1 Failure Data Collection & Analysis

Failure Data indicates 200+ cases of clamp lose due to residual torque loss which results in unplanned customer visits-

5.1.1 Illustrated Images of the joints under study:

a) Type of Orientation & Type of Tightening Joint at both ends of a hose

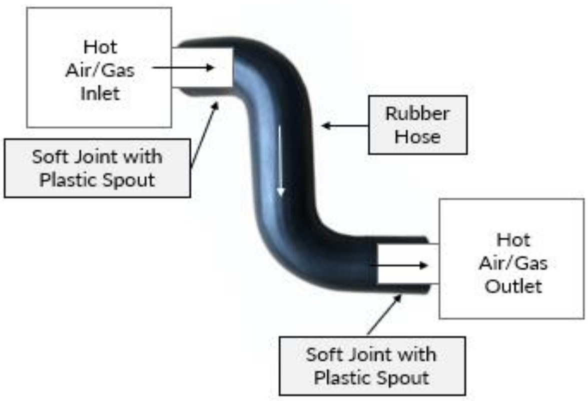


Fig 2 – Schematic diagram for a rubber hose used in pressure application

b) Type of Hose Material & Clamp used:

1. Screw/Band Clamps: are used for idle to moderate pressure application.
2. Hose material: Rubber hoses are widely used for it's flexibility & durability in common application of an automotive system for transferring of coolant & gases.

5.1.2 Analysis Data shows Torque Data of Failed Tightened Joint in current Scenario & it's residual Torque after certain Time period.

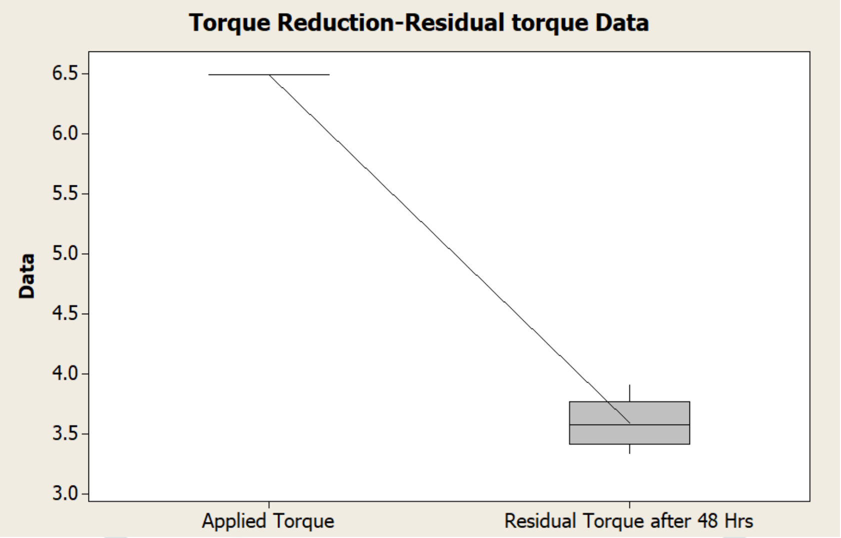


Fig 3 – Loss of residual torque post application

5.1.3 Illustrated Image Shows Grip Length of Rubber hose on to Plastic Spout & It's integration.

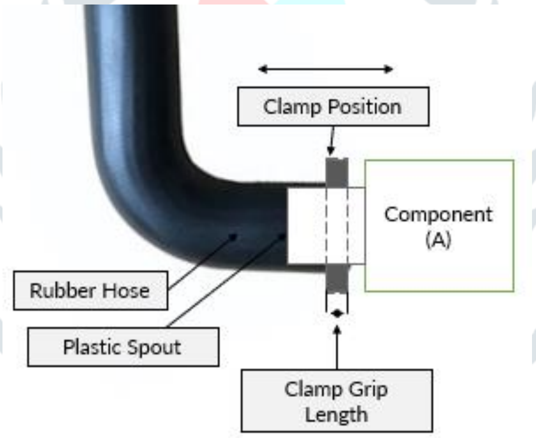


Fig 4 – Construction details

5.2 Root Cause Analysis

As per All the Data Taken & Analysis of Data below are the major Potential Root cause identified

a. Hose Clamping not Achieved due to Over Riding of Clamp onto Plastic Spout creating less Grip strength.
b. Unwanted oil traces/ residues on clamps
c. Deterioration of Residual Torque within initial phase of tightening.

5.2.1 Fish Bone diagram is made followed by Hypothesis & validation of each potential root cause to address the failure with respect to all the data & failure mode.

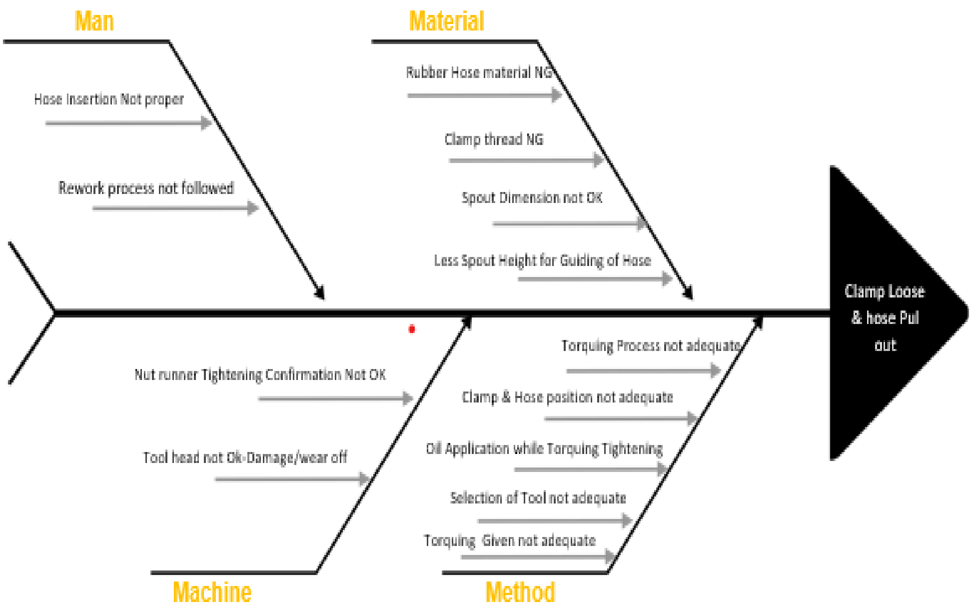


Fig 5 - Ishikawa Diagram

5.3 Solution Identification

Based on all the Root Causes identified some reliable actions are identified:

5.3.1 <u>Hose Clamping not Achieved due to Over Riding of Clamp onto Plastic Spout creating less Grip force</u>

a) For prevention of over-riding of clamp on to Plastic spout- Clamp position to be maintained to a min 5 mm distance -away from Hose end & plastic spout end wall wit this will avoid hose bulging & override on spout causing improper clamping.

b) Increasing the height of Hose Position Locator peep/Notch above the Hose top Portion for preventing Hose clamp position at end & over riding creating improper Clamping.

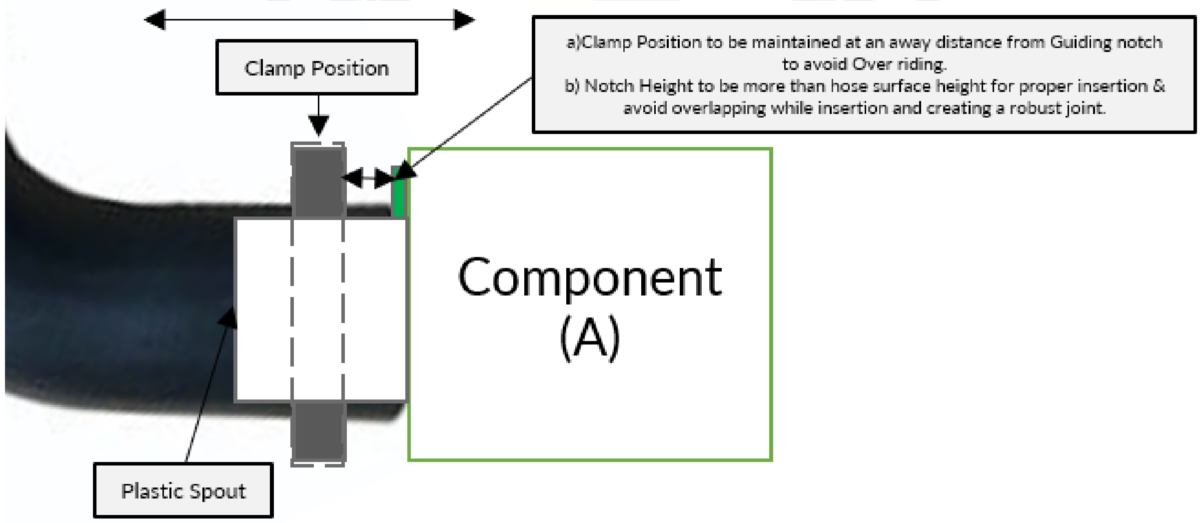


Fig 6- Schematic Diagram for a Hose-Spout interface & layout

5.3.2 <u>Deterioration of Residual Torque within initial phase of tightening</u>

Reducing the RPM of Tightening tool for Increasing Residual torque, with recommendations & trials for Rubber Hose-Plastic Spout Joint, Constant torquing of Joint with lower RPM (< 100 RPM) is done for a 6-7 Nm tightened joint with Constant torquing & Torque Loss of Only 15-20% is observed in comparison to more than 40% of torque less when tightened with Step Torquing or with Constant torquing with more than 300 RPM.

Trials & data taken concludes that while in higher RPM, high frictional losses, high wear of worm in worm clamp results in loosening of the joint. At lower RPM, when torque is applied on the tightened joint, with the force sustained for a longer duration, resulting in a sturdy joint and an improved clamping condition, particularly for softer joints

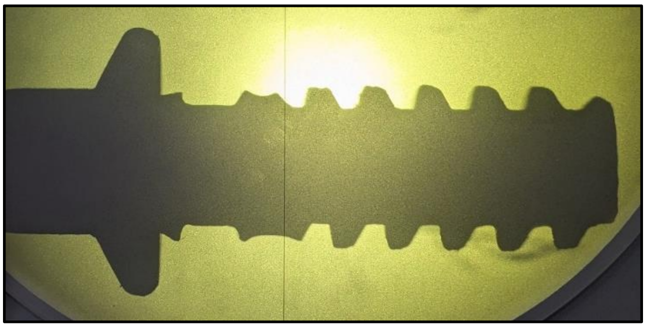


Fig 7 – Thread deformation during tightening with High RPM

5.3.3 Oil Application on clamps

Based on analysis & simulations oil application on softer joints with pressure/Heat Applications can cause issue due to Oil being contributing in less friction between clamp & Tightened surface & thus along with other factors discussed in above Point 1 & 2 can cause clamp to slide or become loose- For the said observation oil cleaning of clamps started before torquing the joint.

5.3.4 Comparison of results

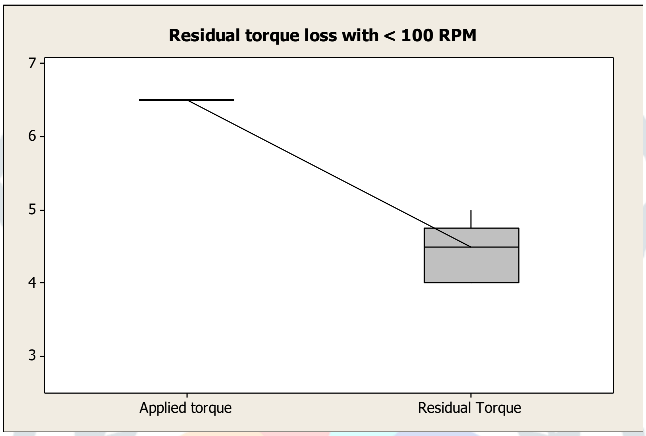


Fig 8 – Torque reduction for < 100 RPM

The above result denotes the torque after 48 hrs in situation where applied torque is reduced to < 100 RPM

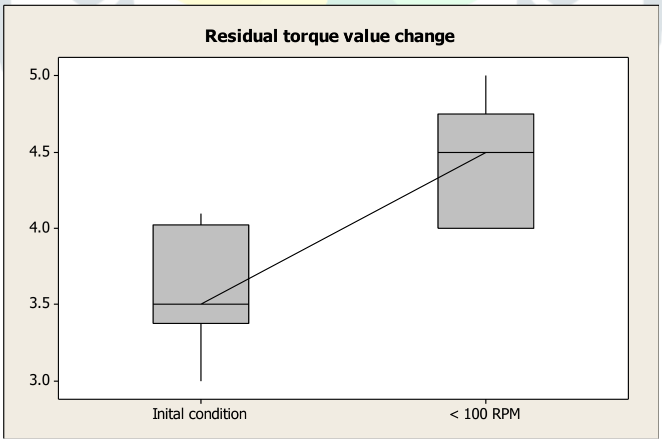


Fig 9 – Comparison of residual torque

The above results denote the improvement in residual after post reduction of RPM to < 100 RPM. Condition (a)-Less than 100 RPM (b)-more than 300 RPM

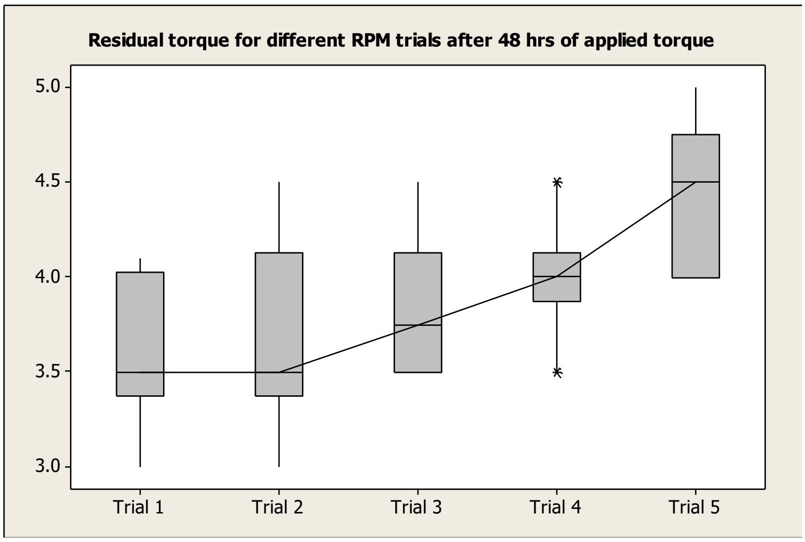


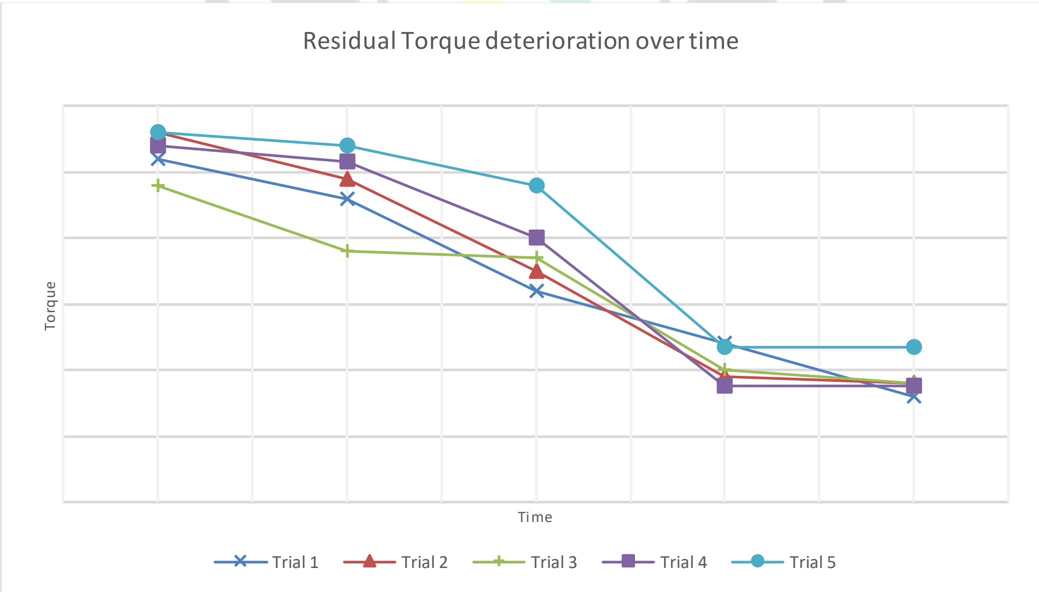
Fig 10 – Result of different torquing strategies deployed

With all above actions taken for all root cause identified all 4 actions are implemented with monitoring of initial 100 batch of samples/assembly for Residual Torque, Overriding of clamps.

Trial 1	Step Torquing	Initial 15% > 600 RPM followed by final 85% of torque >300 RPM
Trial 2	Step Torquing	Initial 30% > 250 RPM followed by final 70 % of torque < 250 RPM
Trial 3	Constant Torquing	Constant torque of < 200 Nm
Trial 4	Step Torquing	Initial 50% > 300 RPM followed by final 50 % of torque < 100 RPM
Trial 5	Constant Torquing	Constant torque of < 100 Nm

Table 1 – Different trails conducted for improving residual torque

Out of the above solutions, Trail 5 has yielded the best result, however considering the required throughput rate requirements, Trail 4 is selected as optimum solution. Selection of lower RPM will result in higher cycle time to achieve the same applied torque which will negatively impact the output quantity.



Graph 1 – Deterioration of residual torque over time

5.4 Solution implementation

5.4.1 Over-riding of clamps is mitigated by introducing mating part interference through an increase in the hose guiding notch height. Additionally, maintaining an appropriate tightening position away from the hose end ensures improved grip of the hose on the mating part surface.

5.4.2 Torque loss, which contributes to clamp loosening and hose disengagement issues, is addressed by optimizing the tightening process with step torquing with lower RPM value (Trail 4). Observations indicate a significant reduction in residual torque loss.

5.4.3 Clamp slippage caused by reduced friction due to oil usage on clamps is resolved by employing oil-free clamps. This is achieved by thoroughly cleaning the clamps before the tightening process.

5.5 Monitoring Results:

Implementation of above torquing scheme resulted in elimination of the hose back out issue from the said joint.

VI. CONCLUSION & FUTURE SCOPE

6.1 Conclusion:

1. Residual torque needs to be studied over time as there is deterioration over period of time.
2. Torquing RPM is a significant process parameter impacting the strength of a soft joint. Lower the torquing RPM, higher will be the residual torque.
3. Overriding of hose also results in weaking of joint strength hence adequate design considerations to be done
4. External influence such as oil/ lubrication also leads to loss of residual torque

With all the 3 actions implemented it clearly shows that the failures has been reduced to zero. Field reporting of such cases for which vehicle going off road are drastically reduced contributing to higher customer satisfaction.

6.2 Future Scope:

Further studies on torque loss will focus on comparing hard and soft joints within the context of vehicle applications. The investigation aims to analyze the impact of reducing RPM, which, while effective in minimizing torque loss, results in increased cycle time. To address this, the feasibility and effectiveness of a step torquing approach will be studied and validated to optimize cycle time while ensuring robust clamping of rubber hoses and soft joints. Additionally, these proposed actions and improvements will be monitored over the vehicle's real-world usage timeframe, with special attention to achieving the targeted mean time to failure (MTTF) to enhance joint reliability and application durability.

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