Assessment of structural behavior of torque converter dampener

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Abstract. A Torque Converter Dampener is a primary component for transmittal of power between the Engine and the Transmission. It comprises of three major components – driving cage plates, driven cage plates and set of springs. Being a spring based system, it provides a smooth conversion of torque from engine to the driveline. When the vehicle performs a gearshift, these springs damp the driveline oscillations and they get locked when the vehicle runs at a higher speed. A Torque Converter Dampener assembly is typically subjected to high torque and centrifugal loading and sometimes, there is a chance of breaking of the springs under operating loading conditions. This paper explains detailed method of analyzing Torque Converter Dampener using Finite Element Analysis. Cage plates and springs are modeled accurately with interactions and boundary conditions properly defined similar to actual hardware, in order to capture the physics of the system. As the problem is highly complex in nature, material non linearity, temperature effect and effect of dynamic fluid pressure are not taken into consideration. The analysis process takes care of the spring’s installation followed by applying centrifugal force and torque in alternating sequence. Similar method is repeated for different spring orientation to find out the worst case model and loading sequence. High stress locations on springs and Driving/Driven cage plates are identified and correlated with the actual hardware test results.

1. Introduction
Torque converters are used in automatic transmissions as torque transfer devices that perform the same purpose as a clutch in a manual transmission vehicle. Without this device, the vehicle would be unable to start or stop without preventing the engine from turning over. A torque converter is a form of fluid coupling that transmits torque while allowing the engine to spin almost independently of the transmission.

The torque converter has a low efficiency because of friction between the working fluid (oil) and mechanical components (impeller, turbine and stator). In order to improve the efficiency of the torque converter, when the slip between the impeller and the turbine is relatively small, the torque converter is locked. This is possible by using a lock-up clutch, which links mechanically the impeller with the turbine. This way there is no more friction between the oil and components, and engine power is mechanically transferred to the gearbox. The lock-up clutch has a vibration dampener, which damps the oscillations during the torque converter lock-up phase. Conventional torque converter dampeners use coil springs to isolate vibration; the energy of the combustion forces is absorbed by the springs and then returned during the compression cycle of the engine.

The Dampeners are typically subjected to cyclic loading resulting in a high probability of spring failure. In this study, static analysis has been performed through Finite Element Analysis to understand the system level behavior of a Dampener under specific loading conditions and predict the springs’ failure by identifying the critical locations.
2. Methodology of torque converter dampener modeling

The torque converter spring dampener to be studied is shown in figure 3 schematically. A dampener primarily is of two types, single stage & 2-stage. [1] In single stage dampener, there are four arc/primary springs which are parallel between TC primary inertia and intermediate retainer. The arc springs are sliding against the holding plate outer wall. In 2-stage dampener, there is another set of linear springs between intermediate retainer and turbine flange and the arc spring set and linear spring set are in series.

3. Spring design parameters

The number of spring segments will determine the dampener structure and dampener maximum travel limit [1]. Because springs are arranged in parallel, more segments will usually produce bigger dampener torque capacity but less dampener travel. There are four spring segments in the system to be studied referring to figure 3. The number of coils in each spring is related with mass distribution and also spring travel.
4. FE analysis of torque converter dampener
A Dampener springs’ orientation in the hardware setup is totally random and it has been observed that failure of the springs are highly dependent on its orientation and the sequence of applied torque and rpm loads. A couple of different spring’s orientation along with different combinations of loading are evaluated to understand the sensitivity of these parameters on springs’ failure. This work is based on a single stage Dampener where four sets of two coaxial springs are placed in parallel. Few hardware failures were observed in the outer coils of the springs, hence static analyses in Abaqus/Standard are performed to understand the structural behavior of the Dampener and identify the critical areas on the spring coils to predict the failures.

In this model, Driving & Driven Plates and springs are considered for the analysis. Modeling software Unigraphics is used to develop 3D geometry model which is meshed using preprocessing tool Hypermesh. Abaqus is used as a solver and postprocessor. The model comprises of first order hexahedral (C3D8I) elements and second order tetrahedral elements (C3D10I). Several surface based and edge based contact interaction have been defined between all interacting interfaces.

4.1 Analysis assumptions
FEA of Torque Converter Dampener becomes complicated because of its high deformation pattern and due to having too many contacts in the model. The computational time is quite high due to higher model size and more number of iterations required to solve each increment. Hence few assumptions have been made to simplify the model, Figure which in turn improves the convergence rate and takes lesser time to solve. For this problem, quarter model with cyclic symmetry has been considered for the analysis and few features which are non-cyclic and would not affect the analysis results, remain ignored. Metal plasticity or post yielding behavior has not been considered as it adds more convergence issues. As failures were observed at the outer spring coils, hence they are modeled accurately with 3D elements whereas the inner spring has been modeled with 1D connector element with equivalent stiffness. Few sharp edges at the contact interfaces have been replaced with small fillets to avoid convergence difficulties. Rivets are not also not modeled explicitly and replaced by 1D rigid elements.

![Figure 4. Simplification of FE Model](image)

4.2 Loads and boundary conditions
As MPC (Multi point constrains) have been created between the center node and the ID nodes for all the plates, boundary conditions applied on these center nodes will control the behaviors of these plates. Being in uninstalled condition in the CAD model, springs need to be installed and preloaded through analysis before applying all the external loads.

In order to do that, spring is compressed by 2 mm from each side by keeping all the plates constrained in all six degrees of freedom followed by unloading the spring and get it installed by its own stiffness. After spring installation, torque & rpm load are applied in two different load steps. Torque in
the form of angular rotation has been applied to the other driving cage plate.

**Figure 5. Load and Boundary Conditions**

### 4.3 Analysis iterations

There are 2 different spring orientations considered for analysis. They are termed as A and B shown in Figure 6. Orientation A has spring’s free end orientated towards ID and Orientation B has the spring’s free end oriented towards OD of the Dampener, as shown in figure 8. Four different load cases are the various combinations of torque and rpm.

**Table1. Shows Four load cases performed on orientation A**

| Cases | Orientation | First Load       | Following Load |
|-------|-------------|------------------|----------------|
| 1     | A           | Max Torque       | -              |
| 2     | A           | Max rpm          | -              |
| 3     | A           | Max Torque       | Max rpm        |
| 4     | A           | Max rpm          | Max Torque     |

Above table shows 4 load cases performed on orientation A. Similar load cases are evaluated for orientation B as well. After analyzing all these 8 cases, the worst case combination needs to be identified and corresponding stress, deflection, contact force results to be reported.

**Figure 6. Details of Orientation (a) Spring free end is towards ID, (b) Spring free end is towards OD**
5. Results

Instead of applying torque on the system, angular rotation has been given to the Driving plate and reaction torque has been measured and compared with the Damper torque-travel curve. From the FE analysis, reaction torque is measured as $T_2$ whereas the actual torque as per the torque-travel curve is $T_1$ for $\theta_3$ degrees of angular rotation. The deviation of $T_2$ from $T_1$ is below 5% and the same may have been caused due to various analysis assumptions and is consistent throughout all the iterations.

![Figure 7. DAMPENER TORQUE-TRAVEL CURVE FEA VS ACTUAL](image)

5.1 Results for Orientation A for Max torque followed by Max rpm

Figure 8 shows some of the stress and contact pressure results for load case 3. As material properties are considered as linear in the analysis, stress values are coming very high. Spring material has a yield limit of 1200 MPa, hence any stress value more than 1200 MPa is damaging for the springs. As shown in Figure 7, location “a” which is 180° from the spring’s free end, has shown some material failure which is correlated to the very high tensile stress (4000 MPa) at the same location. Similarly, the “break point” which is 270° clockwise from the free end, is showing high tensile stress (1400 MPa) in analysis. Also locations “c” and “d” are showing wear in the physical hardware and the similar locations are showing very high contact pressure and contact forces as per the analysis too.

![Figure 8. RESULTS FOR ORIENTATION A FOR MAX TORQUE FOLLOWED BY MAX RPM](image)

5.2 Results for Orientation B for Max torque followed by Max rpm

Figure 9 shows the analysis results for orientation B which has the spring’s free end oriented towards the OD of the dampener. There is a localized high stress location just next to the spring’s free end, which has 2600 MPa compressive von Mises stress. The same location matches quite well with location “b”

![Figure 9. ORIENTATION B FOR MAX TORQUE FOLLOWED BY MAX RPM](image)
from the hardware. The outer surfaces of the spring coils are subjected to high contact pressure and contact forces, which could significantly contribute to the material wear from locations “c” and “d”.

![High contact pressure on the spring coils correlates with material rubbing out from the spring surface](image)

Figure 9. Results for Orientation B for Max torque followed by Max rpm(a) Contact Pressure (CPRESS) plot, (b) Von misses stress plots

6. Conclusions

In this work, structural behavior of a Torque Converter Dampener has been studied for various spring orientations and loads using static analysis. Results are also correlated with the physical hardware test. Following conclusions can be derived from this work.

1. From static analyses on eight iterations, it is found that the combination of torque and rpm is the most damaging load case for Dampener.
2. As mentioned earlier, breaking of springs are highly sensitive towards the spring orientation and it is observed that orientation A caused the spring to break but orientation B doesn’t. Hence orientation A is more critical than B.
3. Irrespective of the spring’s orientation, there are significant material wear on the outer surface of the springs and it is occurred due to the spring’s rubbing off against the cage plates.
4. Significant material wear happened at about 0.5 coils from the end tip because of very high compression against driven plate and localized material yielding.
5. This method can be used to study the system level behavior of Torque Converter Dampener for any transmission. It is also capable to predict the failure in the spring coils for a given orientation, which may potentially replace the physical test.

References

[1] Li, Z and Sandhu, J. “Transmission Torque Converter Arc Spring Dampener Dynamic Characteristics for Driveline Torsional Vibration Evaluation”. SAE Int. J. Passeng. Cars - Mech. Syst. 6(1):2013, doi:10.4271/2013-01-1483