The Use of Optimization Software TOSCA in a Standard Flexplate Design Process

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Abstract: A drive train is only as strong as its weakest link. One of those links is the flexplate. It is used with automatic transmissions to connect the engine to the torque converter/transmission. A flexplate is a thin metal plate that operates at high RPM. Flexplates are optimized for stiffness, strength and mass. Stiffness controls the axial forces transmitted between the engine and transmission. The complexity of flexplate loading from the engine and transmission makes it an ideal candidate for applying optimization techniques for design of a robust plate.

Keywords: Topology, Optimization, Flexplate, Torque converter, Crank flange, Lugs, Strength, Automatic transmission, Design Process, Axial Stiffness, Torsional Stiffness, Bending stiffness, Thrust, Ballooning, Load requirements, Load fluctuations, Torque, Misalignment, Parametric strength factor, Mass Reduction, Lightening holes, Baseline, Symmetry, Constraints, Design Parameters, Design proposals, Hybrid applications, Sensitive, Volume constraint, Design Variant, Feasible

1. Introduction

The Flexplate is the link that transfers power from the automotive engine to the automatic transmission. A typical flexplate assembly consists of a flexplate, ring gear, and retainer plate. In the simulation of the flexplate system, the crank flange, crank bolts, torque converter lugs and lug bolts are included.

Loads are transmitted to the flexplate from the engine through the crank flange and from the torque converter through lugs. During operation, the flexplate experiences three major loads including thrust load coming from the torque converter due to the torque convertor ballooning, engine torque from the crankshaft, and bending moment due to the misalignment of the engine axis with the transmission axis.

Flexplate design varies significantly from one application to another ranging from very small displacement engines with 1-1.5 liters capacity to very large displacement engines with 6-6.5 liters capacity. In addition innovative designs are required to meet new requirements such as,

1. Very low axial stiffness requirements for hybrid applications.
2. High axial movement experienced in racing cars.
3. High torque load requirement in high volume diesel applications & racing cars.

4. High torque load fluctuations seen in line-4 engines where the dynamic torque to mean torque ratio is very high.

Flexplate designs are influenced by the thickness of the plate, cross section profile and most importantly by the shape, size and location of the lightening holes (Figure 1). Lightening holes cut in a flexplate are more sensitive to the design parameters than thickness and cross section profile, so optimizing these holes will help the designer to achieve desired targets quickly. Hence, in many of the cases, the thickness and cross sectional profile is fixed for a flexplate and optimization is done only on the lightening holes.

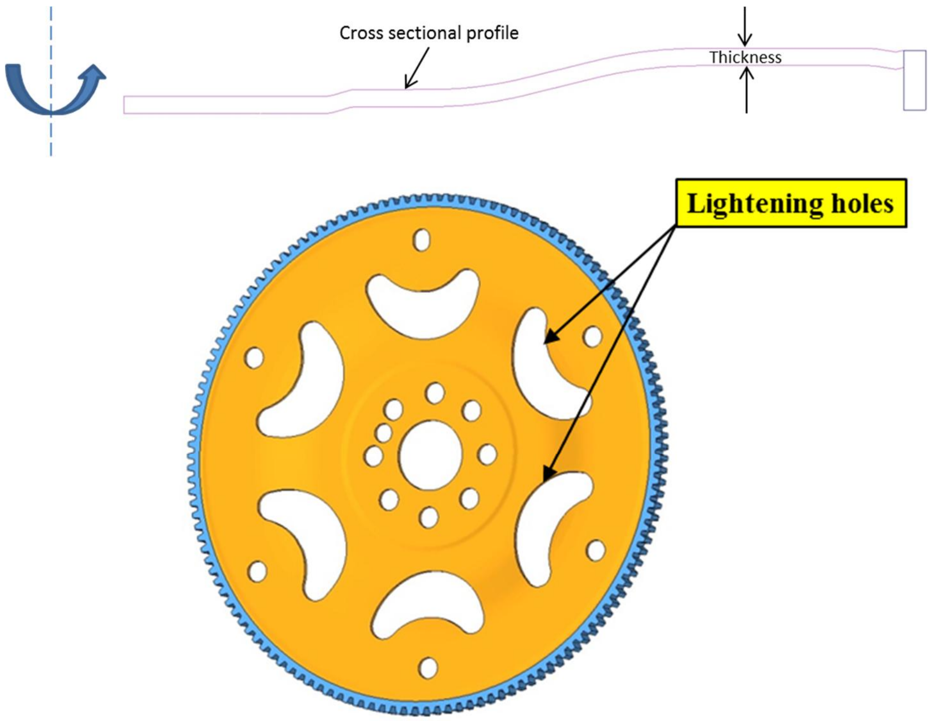


Figure 1. A typical Flexplate showing lightening holes and cross sectional profile

Over a period of time, by experience, a number of traditional lightening hole shapes have been developed and are in use. Figure 2 shows some of the commonly used traditional lightening holes. Determining the sensitive areas to remove the material, determining the optimal location to place the lightening holes and obtaining the first cut shape and size of the lightening holes, manually, by trial and error method is difficult and time consuming.

To expedite the standard design process of a flexplate, there is a need for optimization software to be used in the process which can simultaneously relate different design parameters and suggest design proposals with new innovative lightening hole shapes.

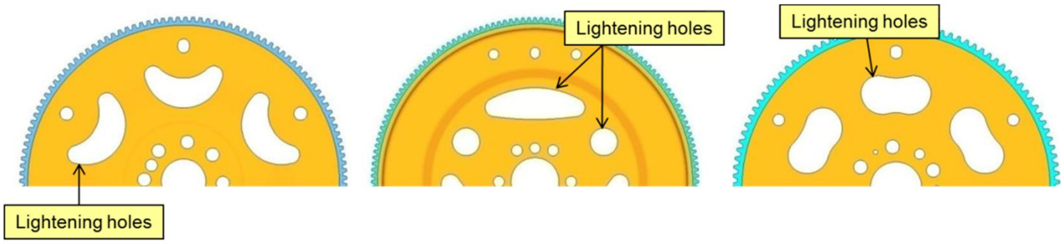


Figure 2. Typical lightening holes in use

2. Topology Optimization of the Flexplate using TOSCA

This section briefly describes the standard process followed in the topology optimization of a flexplate.

A design area is defined on the plate where topology optimization has to be done. Suitable model constraints are defined to avoid asymmetry and unfeasible solutions. A desired range of stiffness constraints is defined as a design parameter in the TOSCA to govern the topology optimization process. The flexplate optimization is carried out by allowing the TOSCA to decide where to remove the material to meet the design requirements. Variants are run with different volume constraints to generate design variants. Only feasible design proposals are taken for further shape optimization.

Flexplates are mainly optimized for stiffness, strength and mass. The following three case studies will demonstrate how optimization software TOSCA (by FE-Design) was used in the design process of a flexplate.

3. Case Study 1: Design Optimization of an Engine Flexplate using TOSCA to improve Parametric Strength Factors

The main objective of this case study was to improve the parametric strength factors in the flexplate at all the critical locations. The lowest parametric strength factor observed at the lightening holes in the baseline design of this flexplate was less than the desired target. In addition, the iterations carried out with traditional lightening hole shapes did not show considerable improvement in the parametric strength factors. Optimization software TOSCA was used to search for a new solution. The baseline design is shown in Figure 3.

Designs suggested by TOSCA (Figure 4) indicated stiffness sensitive areas on the plate, initial shape & position for the lightening holes, and also indicated the amount of material to be removed between adjacent lightening holes at inner and outer sections.

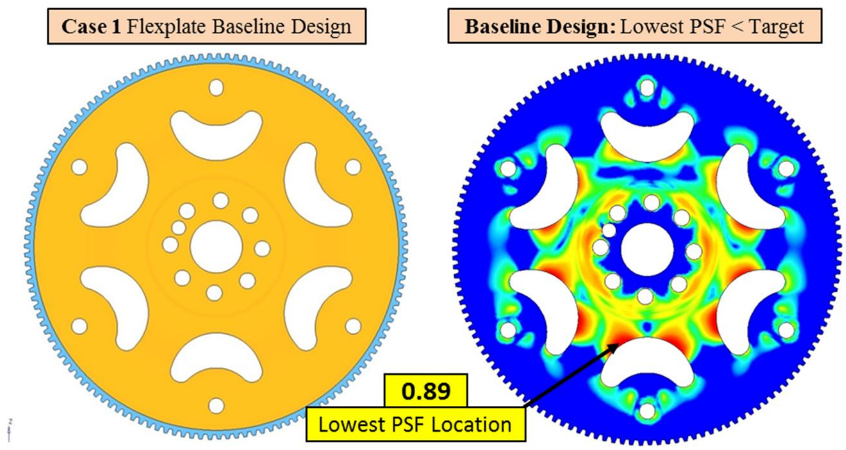
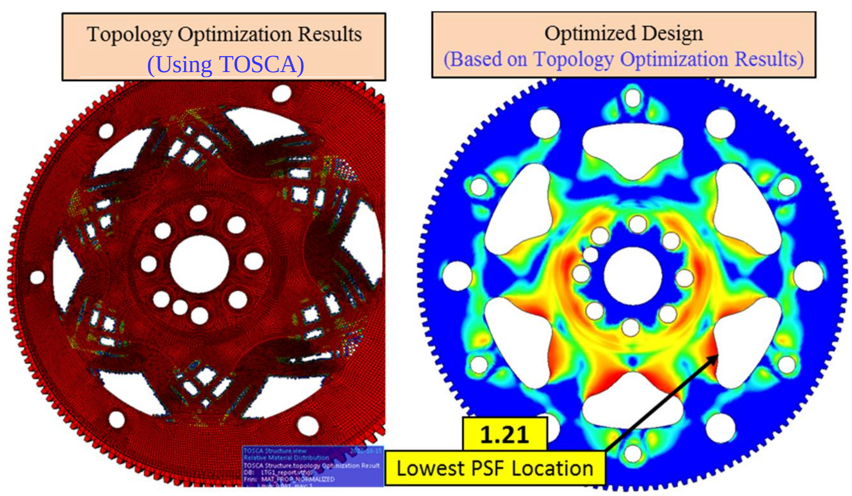


Figure 3. Case 1 flexplate baseline design



~37% improvement in the lowest parametric strength factor was observed in the optimized design compared to the baseline design

Figure 4. Optimized design based on the Topology optimization results

The optimized design developed, based on the lightening hole shape suggested by TOSCA, showed significant (~37%) improvement to the lowest parametric strength factor compared to the baseline design.

4. Case Study 2: Design Optimization of an Engine Flexplate using TOSCA for Mass reduction

The main objective of this case study was to reduce the mass of flexplate (Figure 5) using TOSCA without affecting the parametric strength factors (strength requirements) at the primary lightening holes. It was observed that there is an opportunity for mass reduction in this flexplate by increasing the size of secondary lightening holes.

Iterations were carried out with different volume constraints such that the TOSCA removes more material at the secondary lightening holes without affecting the parametric strength factors at the primary lightening holes.

The optimized design based on the topology optimization results showed considerable (~180gm, 11%) mass reduction compared to the baseline design as shown in Figure 6. Also, no significant change in the parametric strength factors at the primary lightening holes was observed in the optimized design compared to the baseline design. The total time taken for design optimization was significantly reduced with the help of TOSCA.

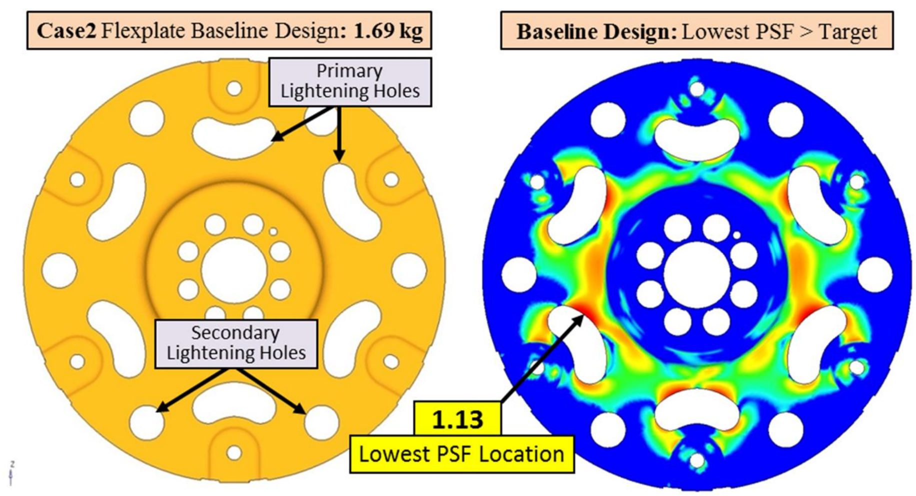


Figure 5. Case 2 flexplate baseline design: 1.69kg

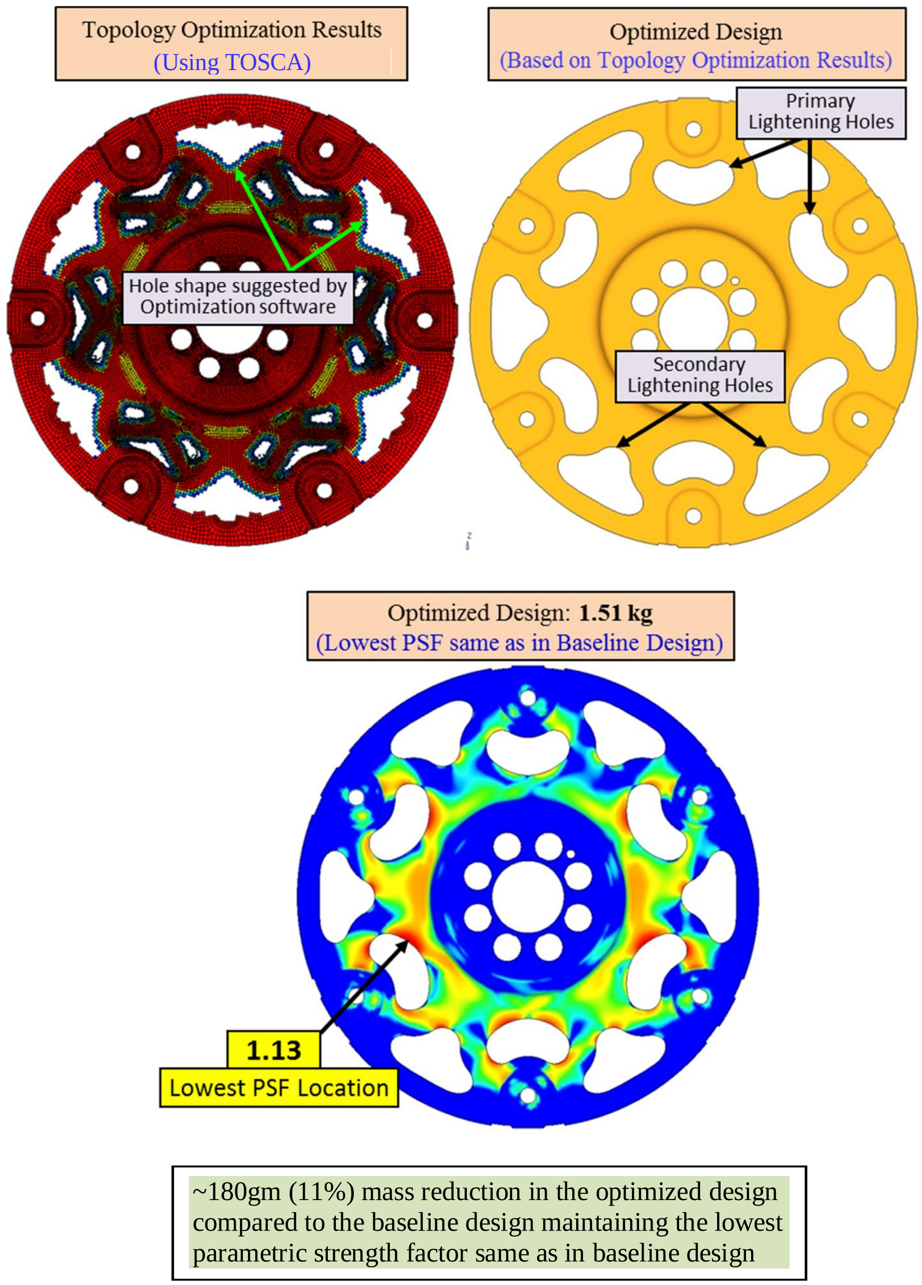


Figure 6. Optimized design based on the Topology optimization results: 1.51 kg

5. Case Study 3: Shape Optimization of a Flexplate using TOSCA for local Stress Reduction

The main objective of this case study was to reduce the stresses of a flexplate and thereby improve the parametric strength factors using TOSCA, through small local geometry changes without affecting the flex rate. The optimization was carried out based on maximum principal stresses as a local design response. Several load cases were considered simultaneously with different stress limits.

The design proposal shows small but effective changes that result in a better stress distribution. Axial stiffness and mass were minimally affected. In this case study, the maximum principal stresses of the torque load case which mainly dominates the fatigue behavior of a flexplate were reduced.

In comparison to the baseline design, a 20% reduction in the peak torque stress and a 13% improvement in the lowest parametric strength factor were observed in the optimized design suggested by the software (Figures 7 & 8). The total time taken for design optimization was significantly reduced with the help of TOSCA.

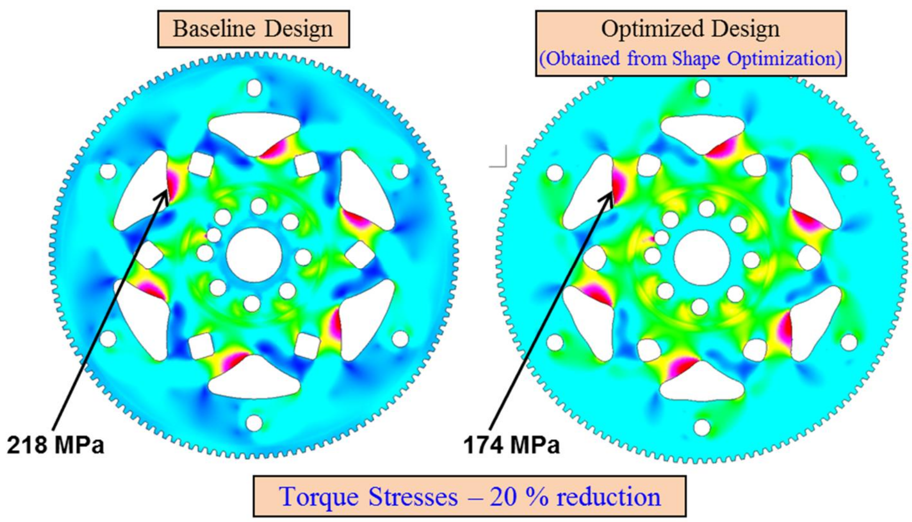


Figure 7. Shape optimization to reduce torque stresses

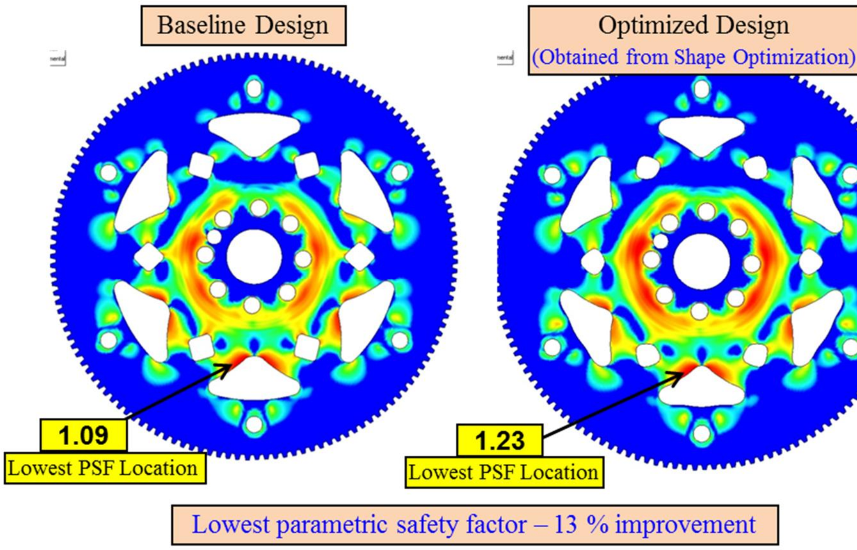


Figure 8. Shape optimization – Fatigue analysis results

6. Outlook: Design Optimization based on Fatigue Results

An extension of the stress based optimization in the design process is the direct integration of fatigue results as design response in the optimization loop with TOSCA. The TOSCA can automatically including a fatigue run after each design iteration and use parametric strength factors or damage results as a design response (Figure 9).

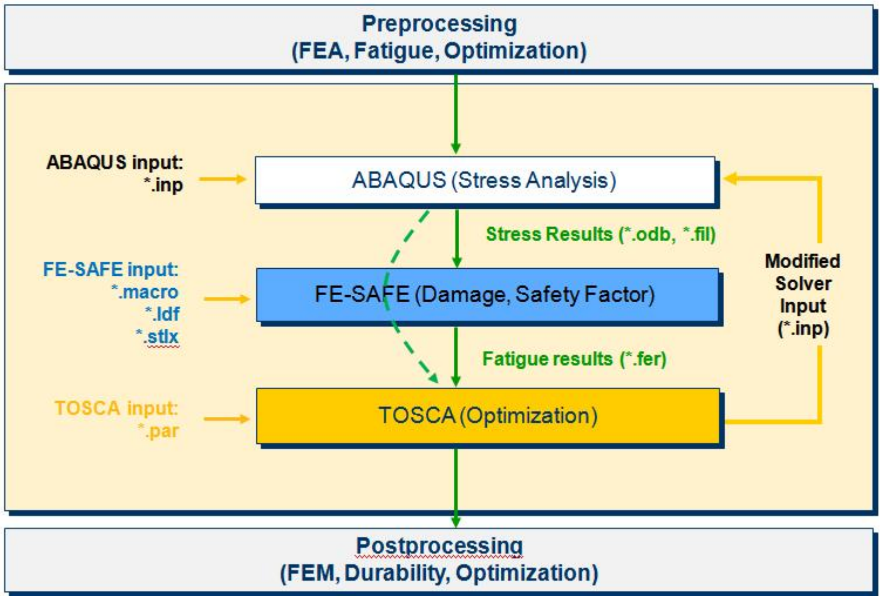


Figure 8. Shape Optimization including Fatigue Results

7. Benefits of using TOSCA in the Standard Flexplate Design Process

From the case studies, the following benefits of using TOSCA in the standard flexplate design process are observed,

- Identifies the areas sensitive to the stiffness of the plate in axial, rotational and bending directions.
- Identifies the areas to remove material for mass reduction without affecting the design requirements.
- Suggests new innovative lightening hole shapes.
- Provides quick first cut solutions, which gives preliminary directions for shape, size and location of lightening holes.

8. Limitations

The success of topology optimization using TOSCA mostly depends on,

1. How well the user sets up the model.
2. The loads considered in the analysis.
3. How well the user defines the constraints for optimization.