**USING INSPIRE AS AN UPFRONT DESIGN, OPTIMIZATION & SIMULATION TOOL FOR EXISTING MANUAL GEARBOX COMPONENTS**

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**Abbreviations:** GSL Gear Shift Linkage, FOS Factor of safety, PTO Power Take of

**Keywords:** NVH, Deflection, tumbling

**Abstract**

In today's practice design and simulation are done on different tool by different people. Most of the time designers are notified only for the problematic zone and not for overdesign area. Product conceptualization was based on the past experiences, benchmarks has no enough base for concept selection. The biggest GAP between the designer and CAE analyst is something that adds on the development cycle of any product. In conventional development cycle, CAE analyst can start his work once he got the design ready by designer. Solid thinking Inspire is the tool plays a vital role in bridging the GAP between design and CAE analyst. Designers can use this tool as an upfront Concept Design, Optimization & Simulation tool & can contribute to minimizing the iterative cycles between designers & CAE teams. Inspire is a great tool for generation of structurally efficient concepts & light-weighting.

In this paper, we tried using Inspire as a tool for the designer where it can assist him in improving product performance characteristics by redesigning it. Two components were taken up in this study, one of the Power transmission (PTO) cover (sheet-metal) & another of a Gear shift fork. PTO cover was to be redesigned to improve vibration characteristics. Gear shift fork was also to be redesigned to eliminate increased gear-shift effort. Inspire was used to find out the best possible structurally efficient design considering the Design Variables, Constraints & Objectives. The concepts suggested by Inspire were validated within Inspire & as well as with the CAE teams for the desired set objectives.

**Introduction**

Solidthinking Inspire is very easy tool that start participating in design and development, right from the design conceiving stage and comes out with fully optimized design in terms of weight & Cost optimization. Today designers must ensure that apart from structural performance, there products continuously improve on aesthetics, weight & performance characteristics, where Inspire as a tool proved to be helpful. Two components were taken up in this study, PTO Cover & Gear Shift Fork.

![Figure 1: Components Identified to work on with Inspire](image-url)
PTO Cover: This is a sheet-metal cover plate bolted over the Power transmission unit. It is used for the maintenance purpose as well to access the inside of the transmission unit. When NVH characteristics of the PTO unit were studied, it was found that one of the main contributors to noise was this plate cover. There are no structural loads during the vehicle operation on this plate, only it is subjected to the excitations/vibrations from transmission. Also, the oil splashing inside the transmission unit hitting this plate from inside could play a role. The existing design had some linear bead pattern as can be seen in Fig 2. The objective was to redesign this PTO cover with added stiffness for improved noise characteristics.

Gear Shift Fork: This one was a Forged component, which is assembled inside the Gear train, & subjected to axial loadings on the contact pads at the bottom of the two legs during gear shift. It was experienced that there was slightly more effort needed in shifting the gears & post studying it was found that it could be due to excessive deflection of the legs of the Fork. The deflection limits, as well as the deflection difference between the two legs play an important role in overall functioning of Gear Shift Fork & the effort needed for shifting the gears. So it was decided to redesign the Fork using Inspire.

Inspire was used as a tool by Designer in trying to redesign the above two components in order to improve the performance attributes as mentioned above.

Process Methodology

Inspire can be used right from the concept stage of any Product development, but as in our scenario, Products were already developed & as there is always a continuous strive to improve the products we came across Inspire & thought it could be of great help in even improving our existing designs. Below is the high-level flow of the overall approach used:

- Baseline Analysis: Perform Simulation of Existing Design
- Geometric De-featureing: Design Package Space creation
- Optimization Setup: Problem setup- Clean sheet/Carryover
- Concept Generation: Inspire generates concepts with provided conditions.
- Concept Validation: Inspire for New Design Analysis
- Detailed Design: Output of Inspire to CAD tools for Detailing
- Manufacturing Feasibility: Check with tools like Inspire Stamping; C2C etc.

Go For: CAE→ Proto→ Testing→ Production

Figure 4: High level Flow of the Overall Approach used in Inspire.
Overall, we followed the approach which Inspire also recommends for this kind of scenario, where we perform a Baseline analysis of the existing product to understand its behavior, improvement areas & also to explore if there is any scope for further weight reduction. Once that is done the existing design is simplified by removing most of the geometric details & trying to have the maximum material in the whole design-space of the Product so that Inspire have more freedom to provide us better designs. Once Optimization is run in Inspire & optimized designs are attained, they can be validated as well within Inspire. Once validated the shortlisted concepts can be pass-on to the Designers for detailed design over the concepts achieved. There are some manufacturing feasibility tools as well within Inspire for Forming & Casting which can be used for checking the feasibility from manufacturing point of view.

PTO Cover

The PTO Cover was redesigned using Inspire with the same approach as mentioned above. Obviously before going ahead with redesign, we had to consider certain constraints like the profile of the cover plate should be same as it must be bolted over the Transmission housing at the same bolting holes.

- **Baseline Analysis:** Analysis of the existing cover plate was performed in Inspire to understand its present characteristics. Inspire had all the tools which a designer needs to setup his model for simulations, be to a single part or an assembly including bolt-pretensions, contacts etc. It was found as expected that the most prominent tumbling mode was at the center of the plate. So, it required more stiffness to be added at the center to improve upon this. Second mode was at the edges between the bolts, which was like flapping & could lead to leakage during operation.

![Figure 5: Baseline Analysis.](image)

- **Geometric Defeaturing:** Inspire had good tools to perform quick geometry simplifications/defeaturing’s for setting up the model for optimization. The existing linear bead patterns were converted to a single line for reducing the complexity of the model.

![Figure 6: Defeaturing & Design-Space Creation](image)
defeatured & the whole center part of the plate was taken as the Design space for the Optimizer to provide the best suitable design/bead-pattern.

- **Optimization Setup:** Topography optimization was ran in Inspire to achieve an bead pattern in the defined design-space. Bead related attributes like width, draw angle, depth was provided. As were not clear about our objective Frequency for the Design, we just selected the maximize Frequency option which gives us the best possible bead pattern which maximizes the Frequency along with maximizing the Stiffness as well.

![Figure 7: Topography Optimization Setup](image)

- **New Design:** We wanted to get a bead pattern from Inspire for the above case. There were constraints as well to control the bead directions, but in this case we haven’t put any constrain & wanted the best bead pattern. Inspire provided a very un-usual & innovative Z shaped bead pattern which shown remarkable improvements as the 1st Mode was increased by almost 45%.

![Figure 8: Bead Pattern received from Inspire & Post CAD Detailing](image)

- **Quick Check Tool (Countering the 2nd Mode):** As the Design space was only in the middle & we are not allowing the Inspire to recommend some design changes to counter the 2nd mode which was
at the periphery between the bolt locations. But in these scenarios designers also have some ideas based on their experiences & they can quickly implement them & check in Inspire on how they will impact. Like in this scenario to add the stiffness locally around the edges for countering the 2nd mode, designer bended the edges at the flanges.

**Figure 8: Bead Pattern received from Inspire & Post CAD Detailing**

This also shown remarkable improvement in increasing the frequencies of 2nd Mode. So Inspire a designer can use for quickly validate his ideas as well.

- **Benefits:** The new bead & the bent flange edges shown remarkable improvement in increasing the stiffness of existing design as 1st Mode increased by almost 45% & 2nd Mode by 15%.

- **Manufacturability & Future Scope:** Manufacturing feasibility of the Optimized design with the new bead pattern was done within Inspire for Formability, thinning & wrinkling checks. Post this Design was finetuned little bit to comply with this. Now we are planning to have Proto developed for this concept for further testing's.

**Figure 9: Manufacturability Check within Inspire**

**Gear Shift Fork**

The Gear Shift Fork was redesigned using Inspire with the same approach as mentioned above in Fig 4. It is to be tested for Normal & Abuse Loadcases where forces are applied at the contact pads. Obviously before going ahead with redesign, we had to consider certain constraints like it is a Forged component, material should be same. Also to target the Optimum Stiffness of the legs of Fork we should ensure that the deflections of the legs during the load application should not be more them 0.3 mm & also the deflection difference between the fork legs should be less than 0.1 mm at any instance during the loading.

- **Baseline Analysis:** Analysis of the existing Gear Shift Fork was performed in Inspire to understand its present characteristics for Normal as well as Abuse loadcases. It was noticed that the deflection in the right fork leg was just exceeding the limit of 0.3 & apart from that the major concern was the deflection difference between the two legs which was coming around 0.21 mm & which have to be restricted below 0.1 mm for better performance of the gear shift fork. Stress results were fine, though there was an hot spot on top part of the right leg, but that was well within limits.
- **Geometric Defeaturing**: Gear Shift Fork was defeatured & also material was added to fill the complete allowable Design space (Brown Color in Fig 10).

![Figure 10: Defeaturing & Design Space Creation (Brown Color) of Gear Shift Fork](image)

- **Optimization Setup**: In this case as it was a solid component we ran it for Topology Optimization with the Maximize Stiffness option. The main important aspect here before running the Optimization was to setup the Displacement Constraint at both the fork legs for less than 0.1 mm. This will ensure that the stiffness of the designs we get from Optimization would be such that the ideally the legs would not deflect more than 0.1 mm & there difference also would be 0 to 0.1 mm only.

![Figure 11: Optimization Setup](image)
• **Optimized Design**: Inspire gives the material layout after the Optimization, which was beneficial for the designer as now he got clear idea on where he can remove or add material. He exported the optimized design to his CAD tool & done the detailing.

![Figure 12: Optimized Design, Existing Design & Final Design](image)

• **Benefits**: The final version of the design after optimization was having benefits in terms of Max. Deflections decreased; Deflection difference was well within limits of 0.1mm, Stress was reduced & Weight also reduced.

![Figure 13: Optimized Design validation](image)

**Results Discussions & Benefit Summary**

The identified 2 components were worked upon here in Inspire. PTO cover was to be redesigned to improve vibration characteristics. Gear shift fork was also to be redesigned to eliminate increased gear-shift effort.

- **PTO COVER**: Inspire helped in redesigning the PTO Cover with a new bead pattern at the middle for added stiffness which increased the 1st Mode by 45%. Bending the cover at the flanges also helped in improving the 2nd mode. **Manufacturability** of the concept was also checked.

- **GEAR SHIFT FORK**: The Optimized design achieved through topology Optimization from Inspire, was definitely more stiff & robust, as deflections was decreased by 23%, was 0.5mm which was well within limits of 0.1mm, Stress was reduced by 35% & Weight also reduced by 18%.

Inspire was used to find out the best possible structurally efficient design considering the Design Variables, Constraints & Objectives. The concepts suggested by Inspire were validated within Inspire & as well as with the CAE teams for the desired set objectives. With Inspire Designer start getting into loading requirement of components and not just into packaging requirement which saves time in design iteration and any surprises during CAE analysis. It also reduces the cost of overall development by reducing the iteration in design and the multiple proto development. The Concepts done in this case-studies are under study for Proto development for further testing.
Challenges
Key challenges in undertaking this project initially was to understand the approaches used in optimizations. Controlling the outputs received from optimization.

Future Plans
Proto parts development and validation testing to be plan before final implementation to production. Planning to use this tool for overall vehicle level optimization especially on the drive train components where majority of components are from Casting and forging technology.

Conclusions
Solid thinking Inspire Software Is a very useful tool for a designer, otherwise earlier Designers were more relying on their legacy designs, experience & intuitions. But now with a tool like Inspire, a designer can own the design right from the concept stage & now can more confidently pass on their designs to the next stages ensuring that the design iterations are minimized. Apart from this with this tool they can parallelly work on the value engineering activities for light-weighting, improving existing design performance & eliminating issues.

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References