Abstract- In regular computerized manufacturing environment, the operation order usually starts from the product design and ends with machine operation to convert raw material into final product. It is often essential to reproduce a CAD model of existing part using any digitization techniques, when original drawings or documentation are not available and used for analysis and modifications are required to construct an improved product design. This process of Reverse Engineering here done with the help of Co-ordinate Measuring Machine and 3D scanner for the same component and after the data is acquitted, the capability of remodelling is checked and a detailed comparison of both the processes is done. Even though the same amount of capital was spent on both 3D scanning and CMM, the accuracy achieved after remodelling in 3D scanning is more compared to accuracy achieved in final CAD model, only while considering the process parameters that were considered here while performing the processes. CAE (CFD, FEA, and Acoustics) analysis of the muffler was carried out to understand the product in depth by using the remodeled CAD data. A Generic process was developed to achieve the future 3D scanning projects in the company.

Keywords- CMM, 3D Scanner, CAD Model, CAE, Reverse Engineering, Replacing, CFD.

I. INTRODUCTION

Reverse engineering is the process that identifies an object, a device, or a system technological property by performing a comprehensive analysis of its structure, functions and operations. In mechanical engineering, this process aims to create a virtual 3D model from an existing physical object to duplicate or to enhance it. They are many reasons to use reverse engineering of physical objects. For example, the reverse engineering process will be used if the original design is not supported by sufficient or adequate documentation or if the original CAD model is not appropriate to support modifications and/or standard production methods. In some cases, original manufacturer no longer exists nor manufactures a product, but some requirements remain for that product. Reverse engineering would then help. In the case of worn or damaged components, for which no source of supply is available, reverse engineering building features would also to analyze competitors’ products features, for performance improvement and/or product features, for lack of additional parts (spare parts) or to update obsolete materials or antiquated manufacturing process. In order to create a 3D model of the object, the object must be measured using 3D scanning technologies (CMM, laser scanners, structured light digitizers…). Once the scanning operation is done, it is possible to rebuild the 3D model using 3D CAD, CAM, CAE or other software. Reverse Engineering has been defined as a process for obtaining the technical data of a critical spare component. Computer-aided reverse engineering relies on the use of computer-aided tools for obtaining the part geometry, identifying its material, improving the design, tooling fabrication, manufacturing planning and physical realization. A solid model of the part is backbone for computer-aided reverse engineering. The model data can be exported or imported into CAD/CAE/CAM systems using standard formats such as IGES, STL, VDA and STEP.
1.1 3D-Scanning

As discussed in the introduction 3D scanning is a process which collects the data of a real world object in form of a 3D picture. The 3D scanner used for this project is a Steinbichler COMET L3D. Data collected is translated to 3-dimensional models. Creates a point cloud of geometric samples on the surface of the subject. The points generated can be used to extrapolate the shape of the subject. Emits radiation or light and detects its reflection or radiation passing through the object to probe it. In some cases, no radiation is emitted but relies on detecting reflected ambient radiation. Similar to a camera but collects distance information about surfaces within its field of view. This particular scanner which the project was carried out on had 2 Lenses – One camera and another projector, 2 lasers for guiding the lenses and in general comes with a set of 5 types of lenses according to their square sizes, they are 45mm, 75mm, 100mm, 250mm, 500mm. Some salient features a 3D scanner are, Choice of lens depends on size, complexity and accuracy of the scan of the object. Accuracy decreases as the size of the lens increases. Scan of the objects using a smaller lens is time consuming. It’s mainly done to fix the field of scan of the lens. Calibration is a must when the lenses are changed. Results are best if the machine is calibrated on a daily basis. Calibration process is sensitive to the environment. Calibration is done using calibration plates and calibration sheets. Calibration plates have holes of the same pitch. The three big holes help in determining x, y and z co-ordinate positions. Calibration is done in a number of positions. For scanning, generally it is calibrated in 5 positions.

![Figure 1: Distance between 3D scanner and object](image1)

![Figure 2: Muffler-A](image2)

**Table 1: Scanning process Parameters (condition)**

| Machine used                           | SteinBichler Comet L3D  |
|----------------------------------------|-------------------------|
| Software used                          | Colin 3D                |
| Linear Distance Between axis of 3D scanner and axis of the rotary table | 850mm                   |
| The thickness of the developer measured | 0.05mm                  |
| Lens Used                              | 250mm² area of capture at focus |
| Total time taken for scanning          | 1 Hour 45 mins.         |

1.2 CMM Measurement

As discussed in the introduction, CMM (Co-ordinate Measuring Machine) is also one of the methods used to Reverse Engineer. The CMM technology is comparatively a little older technology. This is a machine which takes readings in six degrees of freedom and displays these readings in mathematical form. This machine can be manually controlled by an operator or it may be computer controlled. Measurements are defined by a probe attached to the third moving axis of this machine. Probes may be mechanical, optical, laser, or white light. The readings obtained are in terms of co-ordinates and these data can be manipulated to obtain an IGES format.
There are a few referencing options that are available in the machine which have been used to measure the characteristics like points, lines, rectangles (planes), circles in 2d and cylinders, cones and spheres are a few example for 3d measuring references.

### Table 2: CMM process parameter

| Machine used       | FaroArm fusion       |
|--------------------|----------------------|
| Software used      | CMM manager          |
| Reference points taken | 95 point references, 52 rectangular references, 4 circular references, 4 cylindrical references. |
| Alignment          | Top left tip of the part. |
| Total time taken for measuring the co-ordinates | 3 hours |

#### 1.3 Re-modelling

This is the section where the STL files are remodeled and reverse engineered to get the CAD file. This CAD file is then used for further CAE processes. There is certain skill involved in remodeling a 3D image to a part model. There are numerous software’s through which it can be done, namely GEOMAGIC, CATIA, UNIGRAPHICS NX, VR MESH, 3D SCANO etc. The software used to reverse engineer here was UNIGRAPHICS NX version 10. Now let us see the steps involved in Reverse Engineering step by step.

a. Importing of STL into a new model in UNIGRAPHICS NX.

b. Aligning the facet body to a certain Co-Ordinate system.

c. Clipping the surface at specific sections and extracting the curves.

d. The extracted curves from STL file would be discontinuous and would not be complete. To overcome this, the extracted curve should be re-constructed using point sets and drawing a spline over it. This has to be continued for all extracted curves.

e. Now, the extracted curves should be split if it is closed. After splitting they have to be joined using the “Rule” option. Using this option a sheet metal layer is formed between the extracted curves.

f. This sheet metal is given the appropriate thickness and thus the part is formed.

Now, here are some sample images of Reverse Engineering of Muffler A:

![Figure 5: Time taken to remodel from CMM: 11 Hours, Time taken to remodel from 3D scanning: 6 Hours.](image-url)
II. PRELIMINARY STUDY

The products dealt with here are silencers of LVE (Light Vehicle Exhaust). The silencers/mufflers of competitor LVE’s are Reverse Engineered for study purpose and to see and understand the technology implemented in the muffler. The study starts with collecting and obtaining the silencer’s information (which vehicle it is used, vehicles details, Engine details, Region it’s marketed in, etc.). This is basically done to understand the component in deep and to know for what conditions it is made for, so that it becomes easier to compare on specific characteristics. The silencer measurements are taken physically before undergoing any process and noted down. The pictures of the muffler are given below:

III. RESULTS AND DISCUSSION

3.1 Comparison

Comparison of both the process on the basis of the process parameters considered while performing the readings/scanning is done, we can see that

Table 3: Process time

| CMM.                        | 3D scanning.                  |
|-----------------------------|-------------------------------|
| Time for Data acquisition : 3Hours | Time for Data acquisition : 1Hour 45Mins |
| Time for Re-Modeling : 10 Hours | Time for Re-Modeling : 6 Hours |

According to the background study, the cost of a 3D scanner machine usage per hour was found to be 3.5 times the cost of CMM usage per hour.

I.e. if CMM /hour = ‘X’ Rs
Then, 3D scanner/hour = ‘3.5X’ Rs ………………………………………..Eq (1)

Whereas the cost of Re-modelling was found to be the same; remodelling cost per hour
For CMM and 3D scanner = ‘Y’ Rs ………………………………………..Eq(2)

Now, adding the total cost, from (1) and (2)
For CMM = (3 * X) + (10 * Y) and 3D scanner = (1.75 *3.5X) + (6 * Y)
By getting the Cost/Hour by the supplier we get…………………………..Eq(3)
X = 1000Rs. And Y= 800Rs…………………………………………………..Eq(4)

So using (3) and (4) we can see that amount spent on both the process is closely the same;

Table 4: Process time

| Total process cost for usage of CMM (Rs.) | Total process cost for usage of 3D scanning (Rs.) |
|------------------------------------------|-----------------------------------------------|
| 11000/-                                  | 10925/-                                       |

Now, let us see the accuracy of the CAD remodelling from the STL file. Below is the picture showing the deviation of remodelling from STL file from CMM Remodelled and 3D scanning. This will define the accuracy of remodelling. Here 1.2mm accuracy is achieved in CMM reading whereas 0.4mm accuracy is achieved in 3D scanning remodelling.

Figure 6: Deviation Report: Scan Data Vs Reverse Engineered CAD model
We can now conclude that, even though the same amount of capital was spent on both 3D scanning and CMM, the accuracy gotten after remodelling in 3D scanning is more, considering the process parameters that both the process were performed under.

3.2 CFD Analysis Report

**Figure 6: CFD report for muffler**

In the picture above we can see the velocity distribution of the gases inside the muffler. We can see that, the mid part where the wool is present the velocity is the lowest, the gas is almost stagnant. Whereas its flows in a high velocity in the tubes, which are meant to be guided for that.

**Figure 7: Streamlines and mass floe split**

Here we can see the path in which the gas flows by the help of streamlines; also we can see the mass flow split due to the turbulence inside the muffler body. 1% of mass flow shifts from Left Hand side outlet to Right Hand side outlet.

**Figure 8: Heat Transfer**

The temperature distribution in and around the muffler in this particular figure is seen. Again the place where the wool is present, there is an absorption of temperature hence its cooler in that particular
region. The temperature at the inlet tips are seen higher as the high temperature gasses from engine and hot end of exhaust, first hits here at this place.

3.3 FEA Report

From the study of Thermo-mechanical simulation, the maximum plastic strain increment found is 4.7% at 2 spots at fillet position in baffle2 as seen below. Except a few spots on baffle2, rest of the points is seen to be safe and below the permit able limit.

![Figure 9: Plastic Strain](image)

3.4 Acoustics Report

The graph shows the loss in the decibel level (transmission loss) for every corresponding frequency. The main purpose of a silencer/muffler is to reduce the noise coming out of the exhaust, which is achieved successfully. The Frequency range chosen is only till 1000Hz because post 1000Hz the result accuracy from the solver reduces.

![Figure 10: Transmission Loss vs Frequency](image)

IV. CONCLUSION

✓ This paper conclude that, even though the same amount of capital was spent on both 3D scanning and CMM, the accuracy achieved after remodelling in 3D scanning is more compared to accuracy achieved in final CAD model, only while considering the process parameters that were considered here while performing the processes.

✓ CAE (CFD, FEA, and Acoustics) analysis of the muffler was carried out to understand the product in depth by using the remodelled CAD data.

✓ A Generic process was developed to achieve the future 3D scanning projects in the company.

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