Use of Digital Checking Fixtures and Scanning Techniques for Reverse Engineering Purposes

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Abstract - **This case study will examine and teach methods for reverse engineering components using incomplete digital scan data, CAD models and a digital checking fixture technique. In this example a commercially available truck leaf spring had its geometry captured in both a deflected and non deflected state. However due to time and scanning constraints, the deflected spring was only partially captured making direct Reverse Engineering (RE) impossible. Once the non deflected spring was modeled the partial scan data was used to generate a digital checking fixture. Using this fixture the non deflected model was altered to generate a very accurate representation of the deflected spring.**

Index Terms – Center for Advanced Vehicle Design and Simulation (CAViDS), Computer Aided Design (CAD), Geometric Dimensioning and Tolerance (GD&T), Reverse Engineering (R.E).

INTRODUCTION

Optical and digital scanners have made Reverse Engineering (R.E.) relatively easy compared to conventional manual measuring techniques. Structured light or lasers are used to map the geometry of a component and that geometry can be digitally recreated using CAD systems. These systems allow for measurement accuracy to be within the thousands, if not tens of thousands, of the inch. However with any new technology there can be draw backs or imperfections. The draw back with scanners is that if the data is incomplete then RE becomes extremely difficult if not impossible without the original component present. This situation could arise if time constraints prevent all of the geometry from being captured by the scanner or if line of sight access isn’t possible. Problems also arise if data is lost or corrupted during file transfers off

This paper will present a technique to help reverse engineer a component with partial scan data. Specifically, this paper will show how to reverse engineer a deflected component using partial data and a non-deflected model. For teaching purposes this paper will present this technique as a practical case study which was used in an actual research project.

METHODOLOGY

The principles of this technique are already firmly grounded and used in the non digital realm. The principles are used in Geometric Dimensioning and Tolerance (GD&T) as well as dimensional metrology. In most practical cases, to determine the dimensions of a deflected part, a fixture is created using known dimensions. Then a non deflected component is placed into the fixture and deformed to meet the desired dimensions. Once deflected, the part can be analyzed and used for various purposes. This process usually involves time intensive operations to generate an actual fixture and also requires the deformed part as reverence. Furthermore, to generate extremely accurate results precision machining and joining operations are required to reproduce a deflection of a thousandths of an inch. Significant cost will go into creating a fixture accurate enough to replicate the circumstances.

A similar methodology is being implemented in digital CAD media. Virtual CAD models are paired with partial scan data to generate a checking fixture in the computer. Then a free state CAD component is modified and manipulated to meet the fixture, thereby accurately representing the deflected component. This technique is faster and cheaper than that of the conventional means and can be conducted numerous times.

For this digital technique primary and secondary datums are located in the object that is to be reproduced. Following this step, CAD primitive shapes are made to represent these datums. Once the primitives are created they are then assembled in a form of a digital checking fixture. The fixture, to be presented in the coming example, is simply a CAD assembly produced in Solidworks.[1] The scan data to be duplicated is overlaid into the fixture for verification to act as both a tertiary datum as well as a measurement reference. The scan data is also used to check deviation after modification. A completed CAD model is then inserted into the fixture and modified till it matches the scan geometry. Along with being much faster and cheaper than actually fabricating a real component fixture, there is one additional bonus. Scanner technology captures extremely tight tolerances and surface deviations therefore making this methods final product extremely precise compared to manual and conventional means.

The following steps are used in order to perform the fixture technique:

- Generate digital X,Y and Z sections of the object
- Locate critical datum features
- Generate parametric primary datum
- Generate parametric secondary datum
- Place datums in CAD assembly
- Overlay digital sections on assembly
- Place part to be deformed in fixture
- Deform component to match datums
- Verify final product for accuracy using scan data

CASE STUDY

In this case study the overall project involved the reverse engineering of a production model Peterbuilt truck. The truck's geometry was captured using digital white light scanning technology and then reproduced into a CAD model. The model would then be used in a dynamic simulation program called ADAMS-car. Once in ADAMS-Car roll over analysis of the truck could be conducted and then analyzed. The resulting data would then be use by the Peterbuilt Company, which produces the truck.

The research was conducted at Western Michigan Universities Center for Advanced Vehicle Design and Simulation (CAViDS) laboratory. The project was tasked to reverse engineer components, verses simply retrieving prior CAD files from the company, in order to factor in manufacturing differences and variances which the ideal CAD files neglect or cannot account for. Those variances made our simulations as accurate as possible to the real manufactured trucks. [2]

Towards the end of the project, several components needed to be clarified or re-created prior to simulation. One of the components which needed to be worked on was the truck's leaf spring assembly. Three scans of the spring assembly were taken for the project. From these scans three models would be generated. One model was of the overall spring assembly in a non-deflected state, resting on the ground, while fully assembled. The second model was of the spring assembly in place on the truck. This second assembly would be deflected but only under assembly conditions. The truck was lifted into the air so that no other weight was placed onto the spring. The third and final model would be of the spring in its deflected resting state, with the truck on the ground and the weight of an unloaded truck bearing down upon it. The three models would be used to help calculate and verify the computer generated spring's motion and deflection as well as to create the initial spring CAD model.

The challenge of creating the computer models would be in the lack of provided information. Scans of the leaf spring assembly were conducted months prior to its CAD duplication and before the need for multiple models would be required or even requested. Complete scans of the leaf spring assembly, in its not deflected state, were conducted. However scans of the mounted spring were either incomplete or obstructed from the scanners view by surrounding components of the truck. The lack of information made direct duplication of the deflected springs directly from the scan data impossible. There was no longer access to the truck itself to allow for rescanning of the desired geometry. Therefore, a method was developed to reproduce the deflected spring using its basic geometry and then modified to meet known dimensions of its deflected counter parts. A digital picture taken of the non deflected spring can be seen below in Figure 1 along with its reverse engineered CAD model.

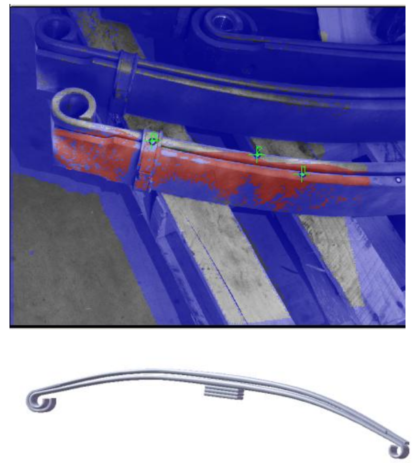

Figure 1
Non Deflected Spring (top) RE CAD Model (bottom)

Though the scans did not allow for direct duplication, they did however capture key areas where the spring was to be mounted relative to other components in its deflected state. Also some geometry of the spring was captured that allowed for referencing based upon mounting points. In other words the scanner revealed datum points and key cross sections of the spring. Enough key points existed that a model of the non deflected spring could be modified and aligned with these points to reproduce its deflected counterpart.

To modify the non deflected model, a form of digital checking fixture was created using the datum points captured in the scan. Like a real life measuring fixture, the datum points would hold the work piece in place while the main cross sections of the spring were bent and manipulated to match the known cross-sections which were captured in the partial scan. The non deformed spring would be manipulated till it would align with the known sections of the deformed spring. Once finalized the deformed spring was then re-inserted into the known scanned geometry to be verified and to calculate percentage error. This technique allows for accurate reproduction because the software changes the model according to how the metal would deform under loading conditions.

Technique Steps

For this project an ATOS II white light scanner was used to scan part geometry. [3] Once scanned, the surface geometry of a part is stored inside the attached software. The ATOS software allows a user to divide up the scanned surface into sections. Too accurately model components in this way, sections along the X, Y and Z axis were made at five millimeter increments. An example of the spring sections along the X-axis can be seen in Figure 2. In this figure the sections are overlaid on the part. When these sections are overlaid on top of one another the entire part can be seen in three dimensions. This is the starting point to this reverse technique.

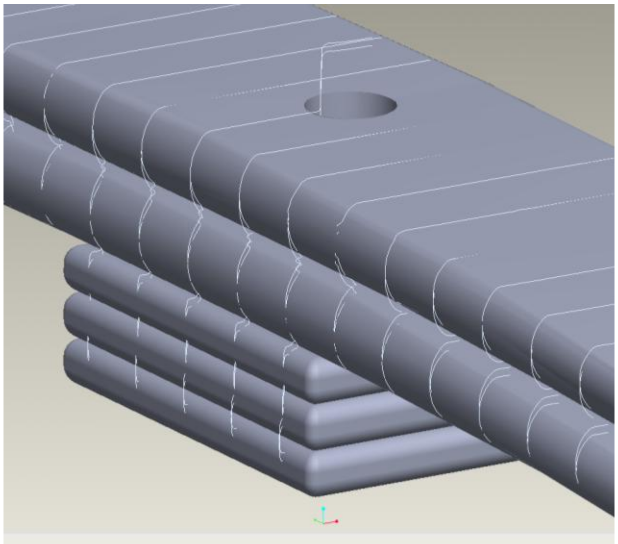

Figure 2
Scan Sections Overlaid on Model

The second step in creating the digital fixture was to locate and identify the main datum reference points, then to create a three dimensional solid primitive to act in its place. In the case of the leaf spring, these points were the two ends of the spring and the top assembly mounts. All three of these primary points are bolt locations and regardless of the amount of deflection, these points will always be bolted in these locations. An example of the described location can be seen highlighted in Figure 3.

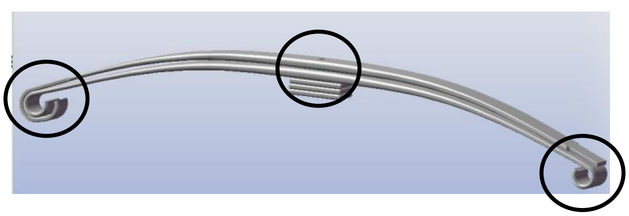

Figure 3
Primary Datum Locations

These points represented the primary datum points. The primitives where made as cylinders, which represented the bolts that affix the spring in reality. All three of the bolts are both a known size and had their geometry captured in all three scans. An example of the finished first step can be seen in Figure4.

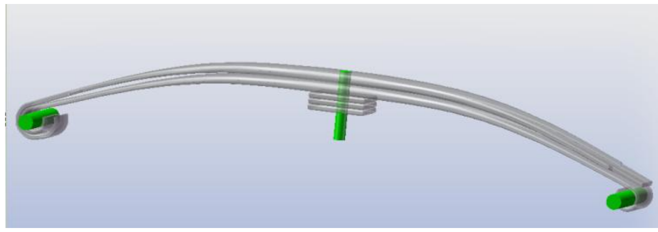

Figure 4
Primitive Cylinders with Spring for Reverence

The third step in creating the fixture was to locate and represent secondary datums. In the springs case the secondary datum would be where surfaces of the spring would come in contact with known surfaces of the truck. For example the leaf spring included a mounting plate which not only reinforced the bolt for the center axle mount but also came in full contact with the axle itself. Also, two mounting plates, which are perpendicular to their mounting bolts at either end of the spring, were located. These are points which, like the bolts from the first step, will never change being in contact. However they are not as critical as the bolt locations because there have larger variances. These surfaces can shift and slide depending on the amount of deflection and how they were assembled. For example the ends of the spring will bolt to the frame of the vehicle and prevent the spring from translation along the X, Y, and Z axis. The surface of the vehicle frame, that the spring is brought up against, prevents translation in only the Z axis and prevents rotation. Because the surface allows for a larger degree of translational movement and is not as critical to the overall design intent, as the bolts, the surfaces are a secondary reference. After locating these points, they were represented in the CAD model by solid surfaces which the spring primitive would be joined against using mate commands. An example of the third step can be seen below in Figure 5.

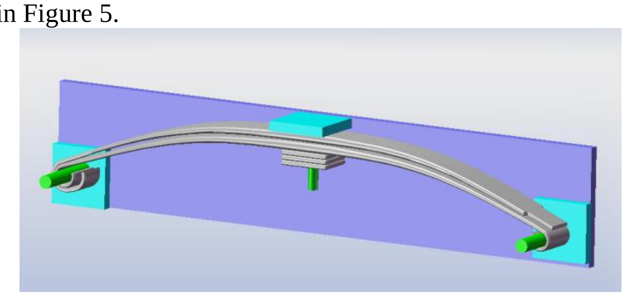

Figure 5
Primary and Secondary Datums with Spring for Reference

The final step in creating the fixture was to import the scanned sections of the deflected leaf spring into the fixture model. The imported sections were transferred into the model as an IGES format. The points were then overlaid onto the already created solid primitives from the previous steps. This newly imported data would serve to act as a guide when transforming the model and to verify the locations found in the previous steps. These cross sections also would act as a tertiary datum point.

Once the fixture was complete and verified using the IGES file, by overlay, the completed assembly of the non-deflected leaf spring was then added to the fixture assembly. Once oriented, one of the main datum points were aligned and affixed to the fixture model as described in Figure 6. From this point the next set of bolt locations were placed.

Using several computerized commands, which allow the model to be deformed without changing its overall dimensions, the other main datums were then aligned and checked for interference. Below in Figure 8 shows the spring after it has been formed to meet the primary and secondary datum points. Once interferences were eliminated for the main datum points, the deforming process was repeated matching the cross section of the spring to the fixture. The cross section allows for very fine geometric deflections to be captured.

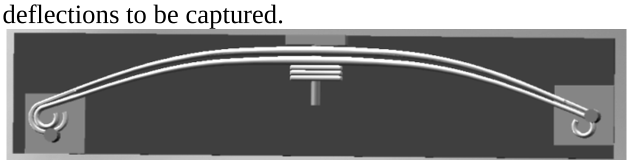

Figure 6
Spring Before Deformation

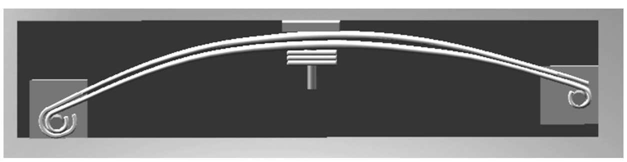

Figure 6
Spring After Deformation (Primary and Secondary Datums)

After this process had been concluded a second interference check was run to see if the spring model came into contact with the imported IGES file. Following a series of minor adjustments, the newly deformed model of the leaf spring now lined up with the reference geometry. The final interference check, with the sections, found that the spring was within less than one thousand of an inch of deviation from the IGES overlay. Given that the scanner being used allowed for greater inaccuracy than the deviation found between the scan data, the model was deemed an acceptable reproduction. This process was repeated to successfully generate the second partially deflected spring.

With the deflected spring complete the CAD model was brought into the ATOS software for a final verification. The raw scan data holds many more data points for comparison than the sections making the verification in ATOS even more reliable than relying on the sections alone. The sections were used due to data transfer and ease of preliminary use however a lot of data is lost in the sectioning process. Therefore it is highly recommended that the actual scanned surfaces be used for final model verification. If an extreme degree of accuracy is not needed for the component then this step can be neglected.

After the desired component is created and verified it can be compared against its counterpart in a Finite Element Analysis (FEA) program in order to determine stress and strain characteristics. In the case of the leaf spring both the non-deflected and deflected models were overlapped in FEA and combined with the known loading of the truck. From this information a stress strain curve was generated and mapped along with a stress distribution along the geometry. Once the stresses and strains are known they can be used to in an extremely accurate representation of how the spring will behave can be made in the dynamic simulation.

CONCLUSION

In the case of the spring the overall process of taking the CAD model and creating the fixture took approximately one hour. An additional hour was needed to both modify the scan sections so that they could be overlaid and to modifying the part for deflection. From start to finish this re-engineering technique took about two hours time making this technique much faster than making doing it manually. Above all this technique allowed the project to be completed without the actual spring present and was far more accurate in its results then manually checking.

This method can be used for any component which has to be deformed for analysis as long as there is a preexisting CAD file along with deflected scan data. Using this technique parts such as beams, springs, cantilevers or irregular geometry solids can be reverse engineered using minimal data.

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