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Integration of Machining with Measurement

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ABSTRACT

Production processes have over time evolved from the use of just CAD to the integration of CAD and CAM technologies to solve the problem of limited productivity and efficiency. This integration while solving the defined need have had to keep up with the ever evolving process of product design and manufacture which now includes the inspection of the finished products to ensure conformity to the design specifications. The stage of product inspection has led to increased bottlenecks in every production process and several manufacturing industries have sought ways to remove these bottlenecks. This paper aims to integrate CAD/CAM with inspection planning to address the limitations being experienced in the area of product manufacture. Using the Siemens NX Computer Aided Engineering application, a CAD model was created which was used by the CAM and Inspection planning tools within Siemens NX to create the machining operations and the inspection plan respectively. The inspection plan on Siemens NX was created and in turn, the DMIS code which contains the inspection program to be conducted by the CMM. The result obtained by the completion of this work is the complete integration of these technologies to increase productivity while optimizing production time.

Keywords: CAD/CAM, Inspection plan, Siemens NX, manufacturing.

1. INTRODUCTION

The goal of any manufacturing operation is to produce parts and components according to the specified design parameters. The use of computers to drive the process of product manufacture has due to continuous improvements provided a means for the objectives of manufacturing to be met as accurately as possible [8]. The use of computers to aid in manufacturing operations in recent times does not just begin and end in the manufacture of the specified product but also encompasses all the processes involved including raw materials procurement, inventory management, scheduling and the actual manufacture of the product and finally inspection.

Presently, the functionality of CAD and CAM for the successful design and manufacture of a component has been integrated to envelop the production life cycle of that component as described in figure 1. This combination of the CAD and CAM functionalities is described as CAD/CAM integration.

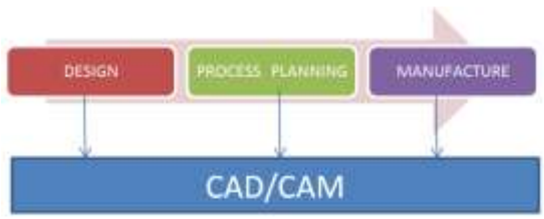

Figure 1 CAD/CAM integration process

The direct consequence of the need for design conformance of manufactured products can be thought of to be described in quality management. The modern approach to quality has over time replaced the notion of acceptable level of defects with a zero-defect philosophy [5]. For total quality for manufactured components to be achieved, there should exist integration between CAD, CAM, and inspection. At the end of the manufacture of a product or component, inspection is carried out to ascertain and verify that the design specifications implemented in the design and manufacture stages have been met.

2. PROBLEM STATEMENT

The establishment of high-quality standards is and will always be the objective of manufacturing industries. These manufacturing industries have sought after different methods to ensure the criteria as mentioned earlier are met. Proper inspection and quality control methods have in time become a necessity rather than a choice in manufacturing operations that intend to be successful [7]. The integration of CAD and CAM technologies currently being implemented in most manufacturing industries still have in them loopholes due to circumstances including human errors, machine failure among others. After-production inspection has been introduced to combat this issue by performing checks to ensure defective and non-conforming parts are identified. Although this inspection is being used, there has been issues including high finished products inventory, high lead time, accuracy issues as well as making the process of inspection energy, time intensive and very expensive. The positive effects including time-saving, accuracy of operation, data sharing capabilities and increased productivity being experienced by manufacturing industries that have successfully utilized the integration of CAD and CAM technologies can be maximized by further integrating CAD/CAM with inspection planning. The integration of inspection with CAD and CAM will eliminate or drastically reduce the loopholes stated earlier in the inspection process. In the traditional method of the manufacturing processes, the product after design using CAD is manufactured using the necessary manufacturing processes before it is queued on a dedicated equipment for inspection [7]. The result of this method is that as the complexity of the product and its manufacturing processes increases, the inspection process becomes less productive and produces more waste. This problem can be addressed by integrating inspection to the CAD/CAM process. This integration as shown in figure 2 is a variation of figure 1 which describes the integration of inspection with CAD/CAM.

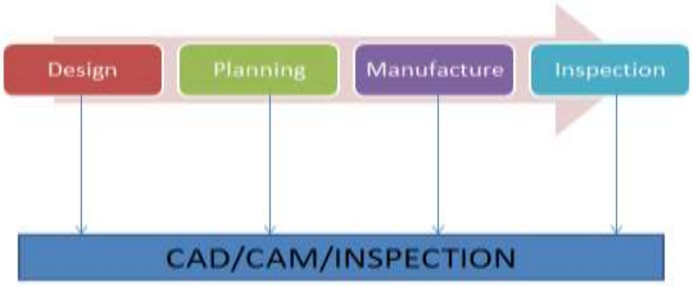

Figure 2: Integration of CAD/CAM and Integration

The integration of inspection with the CAD/CAM process if applied correctly will lead to higher productivity, reduction in inspection time, data sharing capabilities between CAD/ CAM and inspection, increased accuracy, reduction of high work-in-process and reduction of finished product inventory cost.

3. AIM & OBJECTIVES

The aim of this work is to successfully integrate the CNC machining process (CAD/CAM) with inspection. This was achieved with the aid of the Siemens NX software, a CNC machine tool which was used to machine a part used as a case study and a Coordinate Measuring Machine (CMM).

The defined aim of this work was achieved through the subsequent design of a CAD model that was used as a case study. Machining operations were created using Siemens NX CAM. The generation of the G codes which contains the machining instructions to be conducted on the CNC machine tool was completed and subsequent machining of the part was performed. Using the Siemens NX Inspection tool, an inspection plan was developed which contains the features to be measured, inspection paths and tolerances allowed for the part. The inspection plan was post processed to generate the DMIS codes to be executed by the CMM.

4. LITERATURE REVIEW

Inspection of manufactured parts has proven to be an integral aspect of the process of product development. The dimensional inspection of parts has evolved from the use of simple measurement tools to the use of Dimension Measuring Equipment (DME) such as CMMs to ensure the increased accuracy of the process which is paramount. This fact has increased the popularity as well as the use of CMMs as a household means of geometric inspection. For the last two decades, computer-aided inspection planning has been a topic of interest [9]. An inspection plan as defined by [4], is the provision of the dimensioning and tolerancing information of a designed solid model with the aim of generating a program that has the capabilities of conducting an inspection process of the part through the aid of a Coordinate Measuring Machine (CMM). The inspection planning procedure should have the capabilities of determining the necessary plans and information for the measurement of tolerances and dimensions of a manufactured part [1].

Currently, There have been and are still ongoing research in the area of inspection planning processes which continue to develop methods for the purpose of improving the functionality of the integration of CAD/CAM with inspection planning. Figure 3 describes the process of integrating inspection planning with CAD.

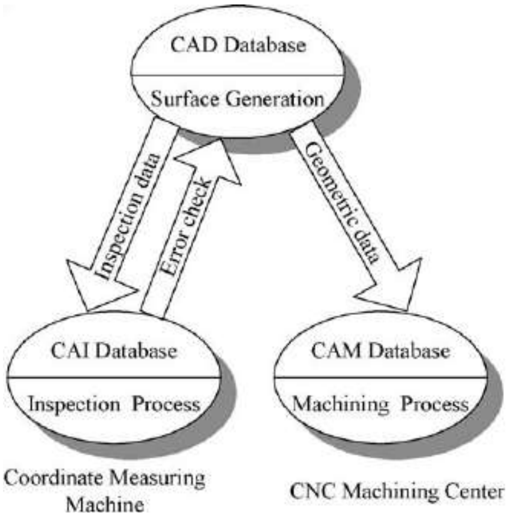

Figure 3: Integration of Inspection planning with CAD, Source: [9]

As described earlier, research has been conducted in the area of CAD, CAM, and CAIP interaction. A paper published by [4] demonstrated works that aim at integrating CAD and Computer Aided Inspection Planning (CAIP) for the inspection planning process using the CMM for the dimensional verification of prismatic parts. The objectives of this work were to address the issues involving the integration of CAD and inspection planning as well as the generation and execution of inspection plans through the incorporation of CAIP with CMM using the DMIS programming code. The methodology adopted by [4] to address the problem was the development of a CAD module, CAIP module, and a CMM module. The proposed methodology on completion was applied to a 3D CAD case study developed using the Mechanical Desktop 6 Power Pack CAD software which served as the CAD module. The features of the model were extracted and geometrically classified using the developed CAIP module and were transferred to the CMM module as a DMIS programming code for inspection thus validating the proposed methodology. In 2014, [2], conducted a research titled 'An Integrated CAPP/CAFD/CAIP System for Prismatic Parts.' CAPP, Computer Aided Fixtures Design (CAFD) and CAIP systems were proposed for the purpose of being integrated into the CAD/CAM system. CAPP system as described by the methodology provides the functions of data extraction, feature recognition and developing a process planning file. The CAFD and CAIP provide the manufacturing setup plan and inspection plans respectively. The CAIP module also generates the DMIS programming code to be used for the CMM. The proposed CAPP/CAFD/CAIP system and the individual functions of the CAPP, CAFD and CAIP is shown in figure 5. This proposed methodology as stated by [2] is suitable for application in the area of 3D printing.

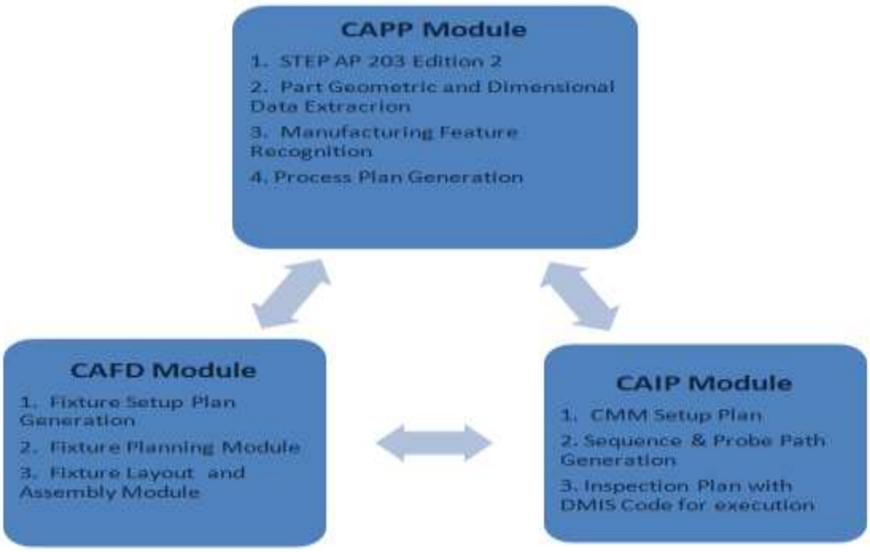

Figure 4: Proposed CAPP/CAFD/CAIP system

A 3D solid model was developed using CATIA V5 CAD software was chosen as the case study for the purpose of validating the CAPP/CAFD/CAIP integration methodology.

5. METHODOLOGY

This section of this paper in detail discusses the sequence of operations required to achieve the aim set out for this work. As described in the introduction of this report, the aim of this work which is to eliminate the existing loophole between machining and geometric inspection by successfully integrating CAD/CAM with inspection. A framework was developed to adequately encompass all the stages involved in production via machining process. Figure 6 represents a flow chart which describes the sequence of operations highlighted above.

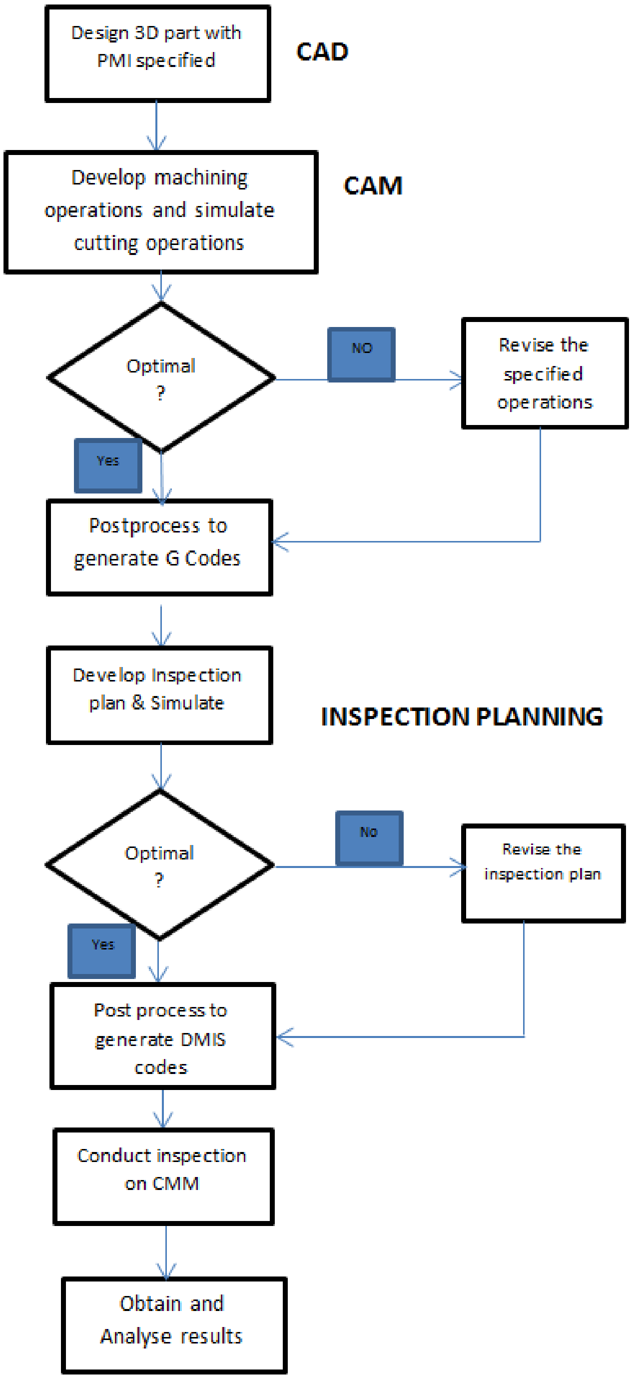

Figure 5: Flow chart for proposed Framework methodology

This work as evident in the objectives is categorized into three parts, design, machining process and geometric inspection using the CAD, CAM and Inspection planning modules respectively.

5.1 Design

A 3D solid model shown in figure 6 was designed using Siemens NX CAD module to be used a case study.

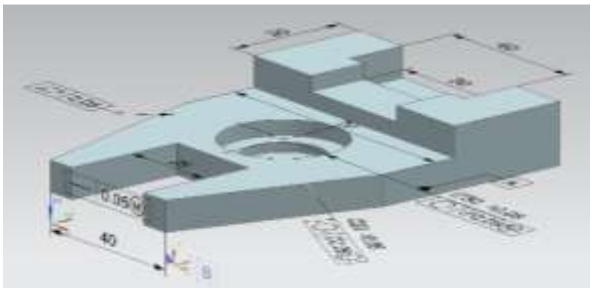

Figure 6: Case study 3D model

For the 3D model described above, the Product and Manufacturing Information (PMI) which is used in CAD to convey the geometric and non-geometric information of a selected geometry or assembly to a third party for the purpose of manufacturing and inspection was incorporated into the design of the model. The information described by the PMI includes tolerances, geometric dimensions, material specifications, surface features, geometric characteristics, surface finish and 3D annotation. In the case of the selected 3D model designed to be used as a case study, the PMI was incorporated into the design to provide information on the geometric dimensions, tolerances, and geometric characteristics.

5.2 Machining process

The creation of the machining operations using a CAM module was performed using the NX CAM. NX CAM is an application within the body of Siemens NX fitted with tools used in creating, modifying and simulating machining operations. The machining process comprises of the machining setup on CAM and the actual machining operation. For the machining setup, the milling operation was specified from a host of operations which includes turning, hole making, drilling, wire electric discharge among others. The milling operation was chosen due to the nature of the part to be cut. The other operations included in the machining setup were, creating or selection of cutting tools, creating cutting operations, machine tool verification and simulation and post processing. The summary of the machining operations generated is shown in table 1.

Table 1: Machining operations summary

	Operation name	**Operation type**	**Tool path**	**Cutting method**	**Cutting tool**	**Machining time**
1.	Face mill rough cut	Cavity milling	Follow path	Rough Cut	8mm mill cutter	01:09:14
2.	Face mill finish cut	Volume based 2.5D milling	Zig zag	Finish cut	8mm mill cutter	00:06:04
3.	Cavity mill for hole	Cavity milling	Follow part	Finish cut	6mm mill cutter	00:02:16
4.	Cavity mill for back slot	Cavity milling	Follow part	Finish cut	6mm mill cutter	00:01:24
5.	Cavity mill for top	Cavity milling	Follow part	Finish cut	6mm mill cutter	00:02:44
6.	Cavity mill for front slot	Cavity milling	Follow periphery	Finish cut	6mm mill cutter	00:01:40
7.	Outer wall first finish	Cavity milling	Follow periphery	Finish cut	8mm mill cutter	00:05:59
8.	Outer wall final finish	Cavity milling	Follow part	Finish cut	8mm mill cutter	00:00:48
						Total: 01:30:44

The NC codes generated using the dedicated post processor developed for the machining of the 3D model was transferred to the Emco 4 axis Heidenhain controlled CNC milling machine which was used to machine to part.

5.3 Inspection planning

At the inspection stage of this work, through the process of programming, an inspection plan was created for the case study 3D model to generate a DMIS programming code with which a direct computer controlled CMM will accurately measure a part and in turn, the measured data will be analyzed using the Siemens NX inspection tool. The created inspection plan performs the function of accurately performing geometric dimensional analysis on the manufactured part through the processes of feature definition, probe path generation and validation, simulation and analysis of measured data.

As regards the case study, a direct computer controlled CMM was not available hence an inspection plan was generated using the Inspect 3D computer software which is a retrofit application used to replace obsolete inspection software to perform improved functions as compared to the previous software mainly to create inspection programs from CAD models. The CMM available was the KEMCO 400 computer assisted 3 axis gantry type CMM.

6. RESULTS AND DISCUSSION

In addition to the machined components, the 3D model was also produced using the 3D printing additive manufacturing method. This was done to demonstrate the effectiveness of the integration of CAD with measurement as well as to show that an accurate inspection program can be developed regardless of the manufacturing process employed to produce the required part. The printed model is shown in figure 7.

Figure 7: Machined and 3D printed model

The inspection results obtained for the inspection is both parts are shown in figure 8 to 11. The red labels show dimensions outside tolerance.

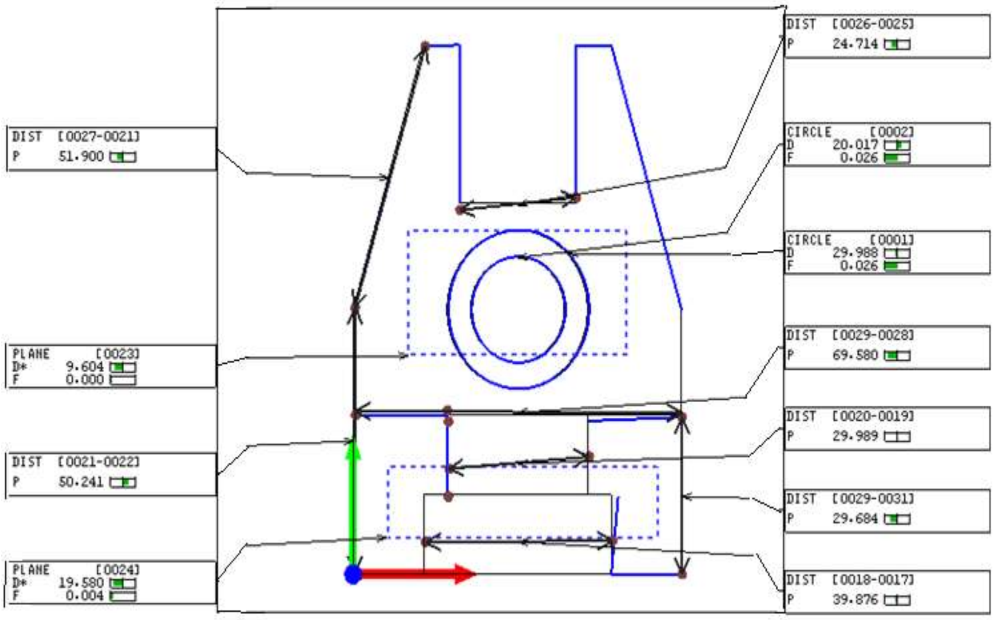

Figure 8: Linear dimensions of machined part

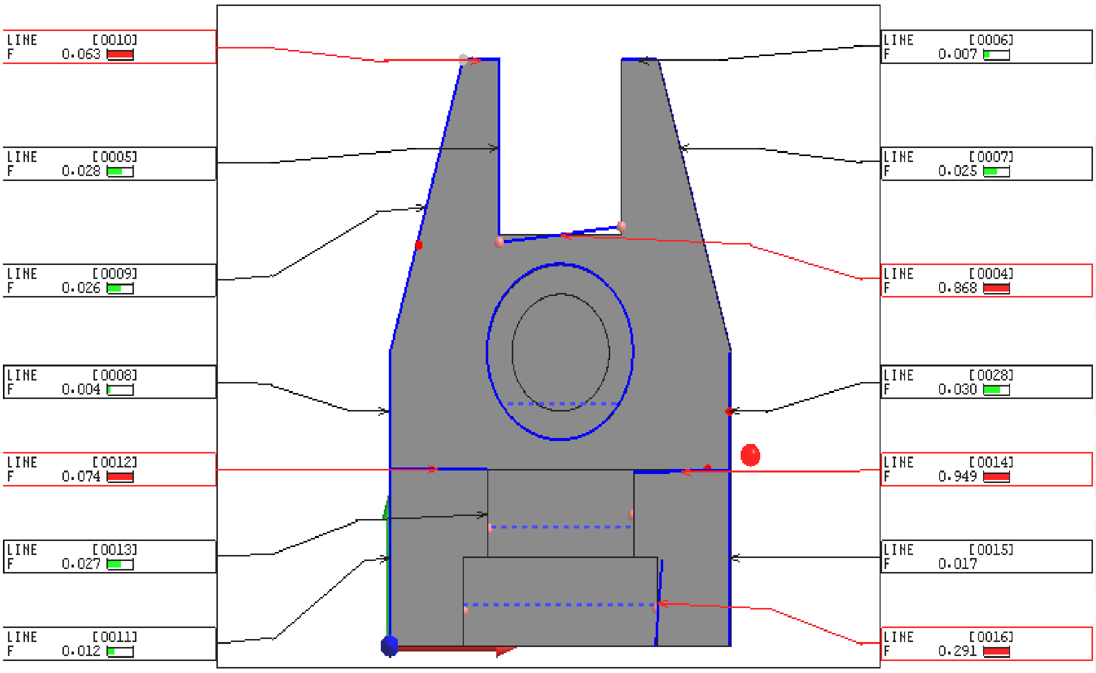

Figure 9: Straightness of selected lines for machined part

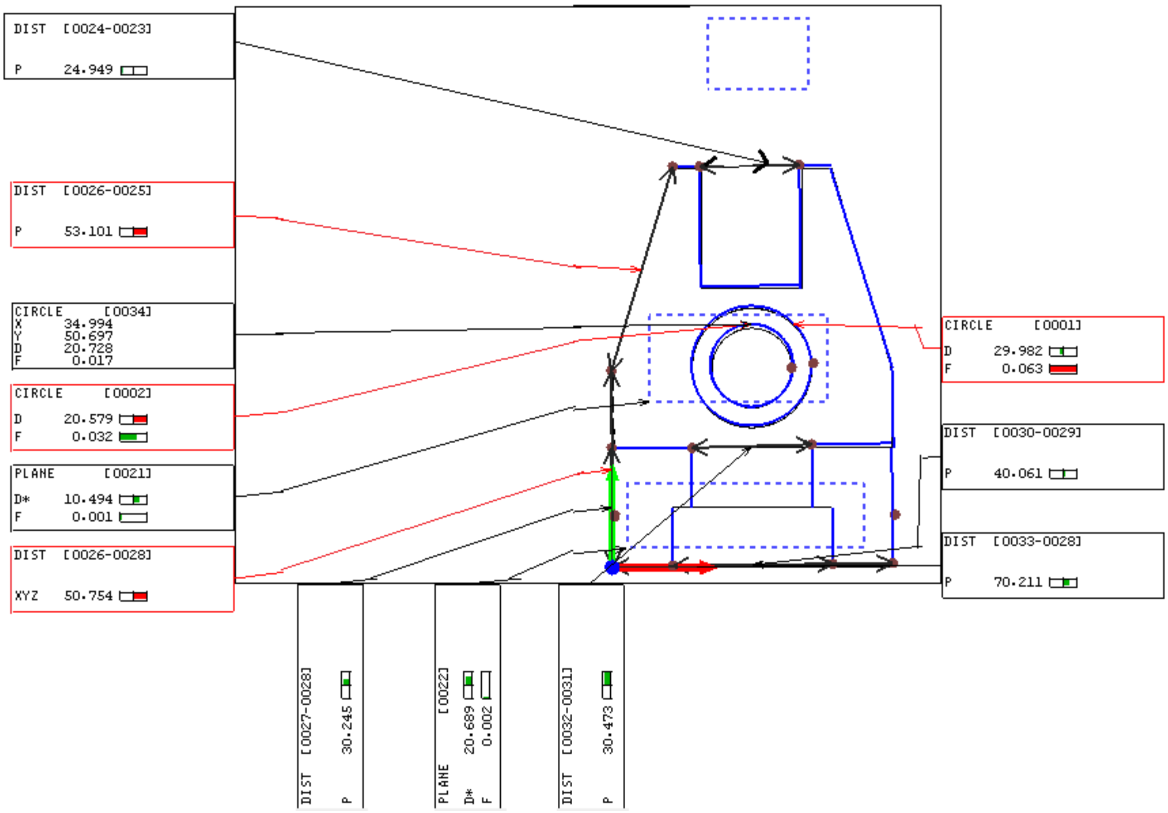

Figure 10: Linear dimensions for 3D printed part

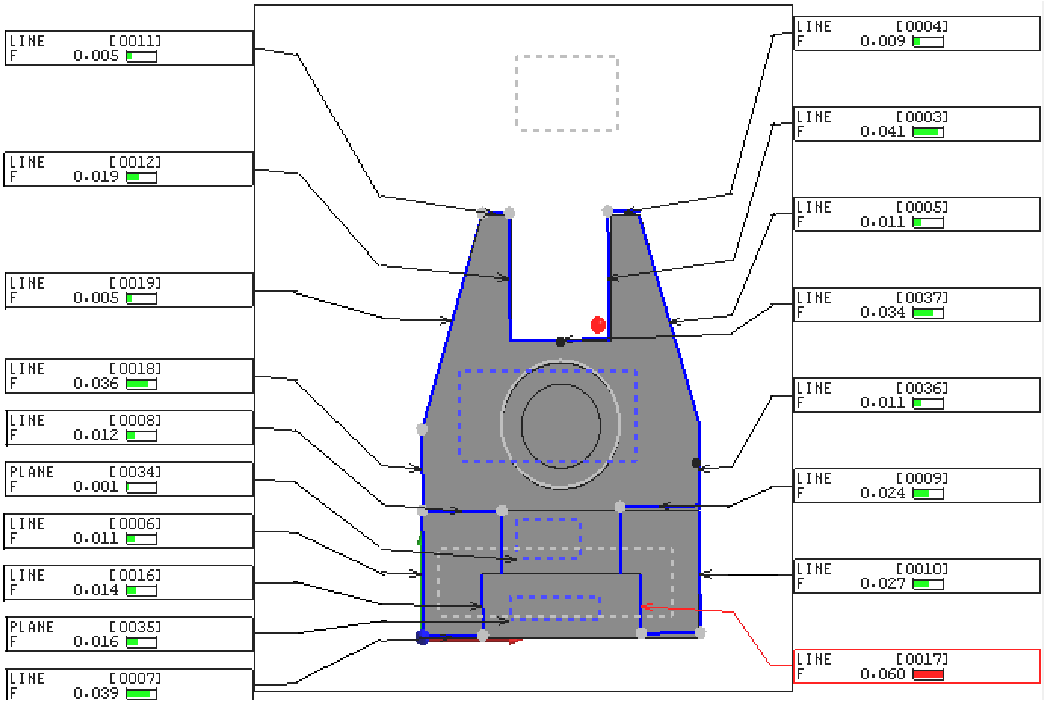

Figure 11: Straightness of selected lines for 3D printed part

The selected geometric characteristics of the features for the manufactured parts investigated by the inspection procedure were circularity which defines the circles of the counterbore, flatness for the planes and finally straightness which defines the lines of the part. The machining operations created to conduct the process of machining are composed of eight operations which began with the creation of a rough cut cavity mill operation designed to perform the function of removing large amount of material in order to produce the required shape before the commencement of the subsequent finishing operations created to cut the counterbore, slots and generally cut the part to the specified tolerance and dimensions. The designed tolerance for the circularity, flatness, and straightness of the part's features are 0.05mm while the tolerance for the all the linear dimensions are ±0.5mm. This is shown in the draft of the 3D model in figure 12.

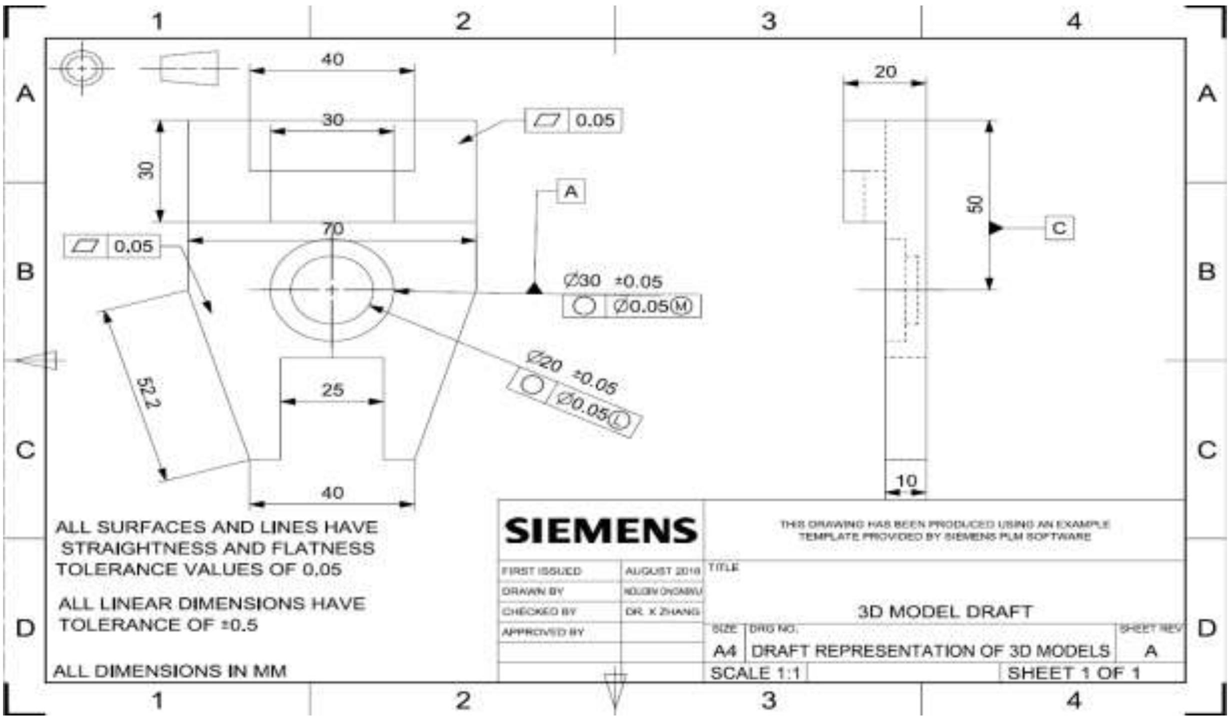

Figure 12: Draft representation of the CAD model

The results obtained for the machined part shows that all the linear dimensions, diameters of the counterbore and height of the part are well with the specified tolerance. In the case of the geometric characteristics also referred to as form, the diameters of the counter bore both have a tolerance of 0.026mm which puts them well within the designed tolerance earlier stated. To obtain the height of the solid, a plane was created on the top surfaces of the part as evident in the results shown in figure 8. This result shows that the middle and the overall height of the part are 19.580mm and 9.604mm respectively putting the results within the design tolerance. The flatness selected for all the four surfaces were all within tolerance. For the straightness of the line features for the part, 5 lines were outside the tolerance value as shown in figure 9. For the 3D printed model, the same features as in the case of the machined part were analyzed based on the results obtained from the inspection using the CMM. This analysis indicated that for the diameters of the counterbore, the large circle is 29.982mm putting it within tolerance but the circularity was reported to be 0.063mm indicating that the form is outside the specified tolerance value. The smaller circle has circularity value of 0.017mm which puts it within tolerance while the diameter is 20.728mm placing it outside the tolerance. The flatness of the surfaces of the part was within tolerance as specified in the results in figure 11. The results obtained from the analysis of the straightness of the line shows that all the lines were within the specified tolerance value except one which had a straightness value of 0.06mm.

7. CONCLUSION

This work describes a methodology capable of performing the function of integrating CAD/CAM technology with inspection planning. The results obtained from the dimensional analysis conducted on both the machined part and the 3D printed part proves that the integration of these technologies can be applied to other manufacturing processes not limited to machining. This will significantly improve the area of production quality control while promoting increased productivity and lean production processes across manufacturing industries.

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