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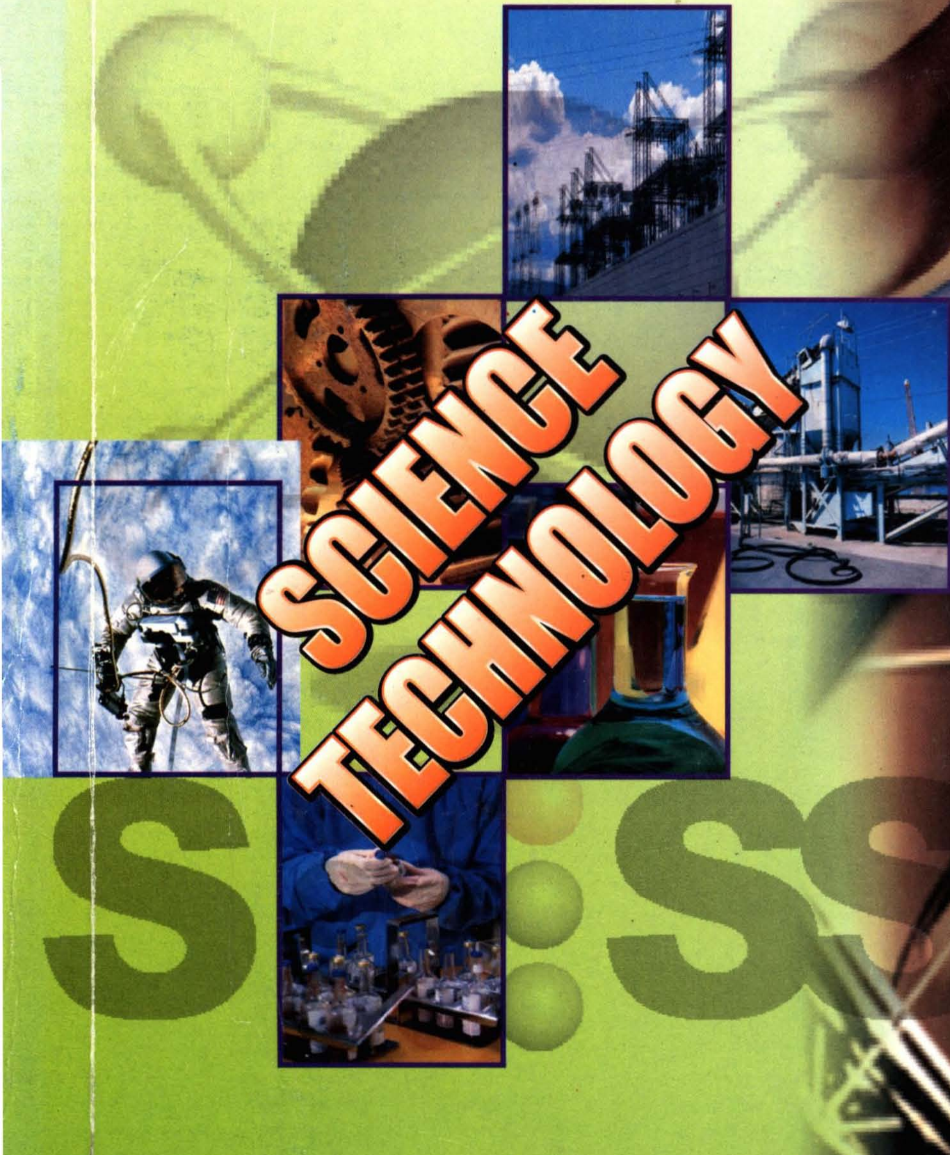

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Reverse Engineering Approach in Developing of a Cam Profile for Internal Combustion Engine

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ABSTRACT

Cam is a device converting a rotational movement to control reciprocating movement through its shape with very high accurate timing. The cam profile regarding displacement and angle information was not available for developing a cam profile model. An approach of reverse engineering was used to develop an original camshaft of internal combustion engine. The process began with finding the coordinate system of cam profile using Coordinate Measurement Machine (CMM). The information was applied to Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) software to prepare Computer Numerical Control (CNC) code. The code was generated to Wire cut Electro Discharge Machine (EDM) for fabricating cam. CMM, CAM and EDM capabilities and problems in developing cam model were also discussed. The result indicated the reverse engineering approach has capability in developing cam profile.

Keywords: *Reverse engineering, cam, measuring, generating and machining*

Introduction

Accurate movement can be controlled by using cam via its follower especially in packaging machines, can-making machine, wire-forming machine, machine mechanism (Borg et al. 1997) and engine (Lampinen 2003). Cam with cam follower controls the rotational movement and converts into reciprocating movement with very high and accurate timing. The valvetrain mechanism takes place as operated device to control the exchange of inlet and exhaust gases in the internal-combustion engine as shown in Figure 1. The valvetrain assembly includes the poppet type valve (inlet or exhaust), the spring which closes it, the force transmission components (cam follower, pushrod, rocker arm) and the cam driving assembly, which transmits the operating force from the engine power output shaft to the camshaft in which the cam is mounted (Lampinen 2003). The function of the cam is to control valve opening and closing movements by its shape with very accurate timing in relation to the stage of the engines operating cycle. Cam shape optimization heavily depends on task, material strength and durability, cam manufacturing technology, geometric, kinetic and dynamics of cam movement. A geometry aspect is an important factor that should be considered in developing cam.

Reverse engineering is a digitally scanning an existing physical model and converting it into a digital model for further manipulation (Schodek et al. 2005). This is a convenient method to visualize and model points when they have been measured. The measurement tools of model depends on the shape complexity either manual or automatic touch device. For simple or regular model the manual or conventional metrology tools can deliver the dimension. However, most of engineering models not only consists of regular shape, but also combination with irregular or complex shape. Digitizers such as Coordinate Measurement Machine (CMM) may be used to input extremely complex shapes and used to develop of the model with current technology utilization of Computer Aided Design (CAD), Computer Aided Manufacturing (CAM) and Computer Numerical Control (CNC) machine. This reverse engineering approach is necessary especially when the design drawings for the product are not available or replacing for an existing part (Schodek et al. 2005; Malek et el. 2005).

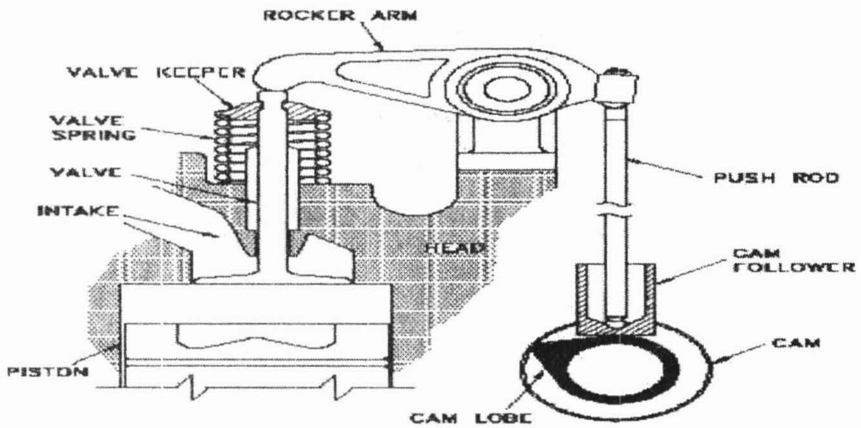


Fig. 1: Cam Assembly in Internal Combustion Engine

The cam profile regarding displacement and angle information was not available. Highly accuracy of cam profile requirement causes suitability and capability of reverse engineering processes. This approach shows capability in modeling and machining turbine blade (Malek et al. 2005) and modeling impeller (Majid & Boay 2005). In this paper, an approach of reverse engineering is applied to develop an original cam of internal combustion engine. Finally fabricating of a cam with similar geometric as original can be succeed when all processes of reverse engineering are applied.

Methodology

An approach of reverse engineering is used to develop an original camshaft of internal combustion engine. The processes begin to retrieve the coordinate system of cam profile with scanning part using Coordinate Measurement Machine (CMM). The information is applied to illustrate geometry part modeling with Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) software is used to prepare G-code for Computer Numerical Control (CNC) machine. The code is transfer into Wire cut Electro Discharge Machine (EDM) for fabricating cam. Overall processes of reverse engineering are shown in Figure 2.

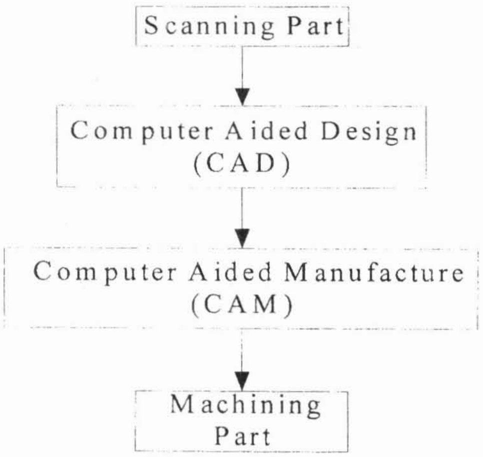
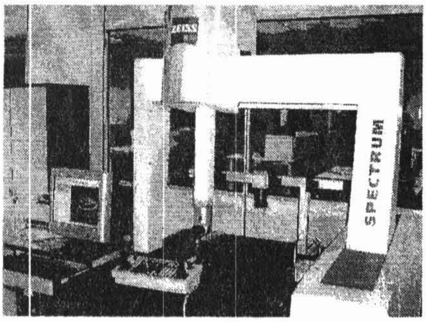
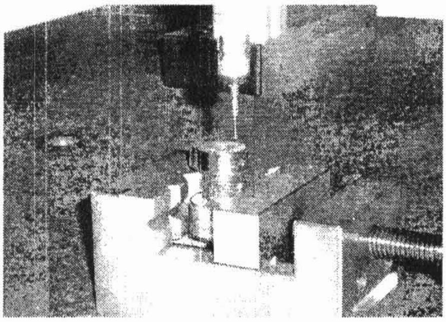


Fig. 2: Reverse Engineering Processes Scanning Part

According to Schodek et al. (2005), there is a variety of contact, or touch type digitizers, including a tabletop manually operated articulated arm capable of digitizing complex shape, an automatic three axis digitizer and a large digitizing bed used in the automobile design process. Figure 3 (a) shows CMM brand Zeiss Spectrum Multi Sensor made in German which is available and used in this project. This is an automatic three axis digitizer with touch probes utilized to gather the polar coordinate of a cam. The scanning process begins with clamping cam on clamping device and calibrated 1 mm diameter ball stylus contact probes ruby material type used to scan the cam as shown in Figure 3 (b). CAD geometries of scan data and initial cam geometry are stored on computer using *Calipso* software.





a) Machine setting b) Cam on clamping device

Fig. 3: Coordinate Measuring Machine (CMM) measuring cam profile

Computer Aided Design (CAD)

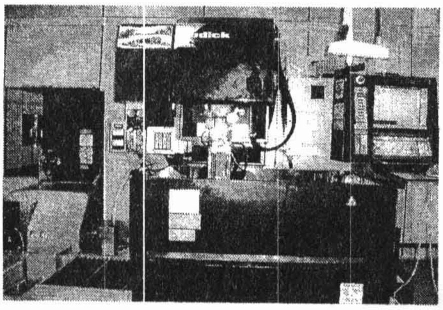
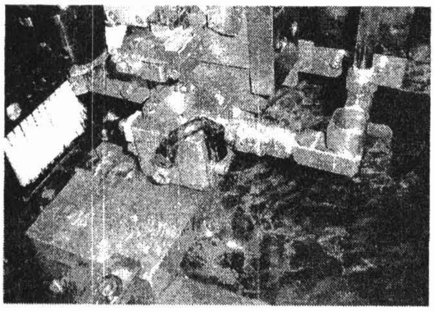
Cimatron E 6.02 Service Pack 2 version 2005 has been selected due to it capability to simulate wire cut machining. Modeling software application creates and edit model from CMM. Data and file from CMM in iges format are modified according to real cam model to produce CAD model using modeling application process.

Computer Aided Manufacturing (CAM)

G code generating is done via CAM application model process that use similar machine in machining cam. Other software inside Cimatron, Fikus Wire EFM & Lathe 122 software has capability to create correct CNC code for Soddick WEDM. A machine parameters need to be defined before generating CAM code for WEDM such as wire diameter, cut width, roughing & finishing path type, wire exit distance and overlap. The important stages in that particular software are tootpath, path, process, calculation, post process and verify. Finally the G code can be generated in verify stage.

Machining Part

Figure 4 (a) shows CNC WEDM machine brand Sodick AQ535L is used to machine aluminum as initial step in developing cam because it is easily to machine. The common work pieces that can be used are chilled cast iron, nodular cast iron high speed tool steel and hardened steel 1050 (Jackson et al. 2001) for cam. In addition, the significant purpose in this study is to show capability of reverse engineering approach an initial step to develop a cam although the manufactures usually used casting, grinding, milling, rolling and powder metallurgy process (Jensen 1987; Blanchard et al. 2000; Hagedorn& Weinert 2004). Machining of work piece starts with rough and ends with finished machining using copper wire size 0.02 mm on clamping system.

a) CNC WEDM settings up b) Work piece machined

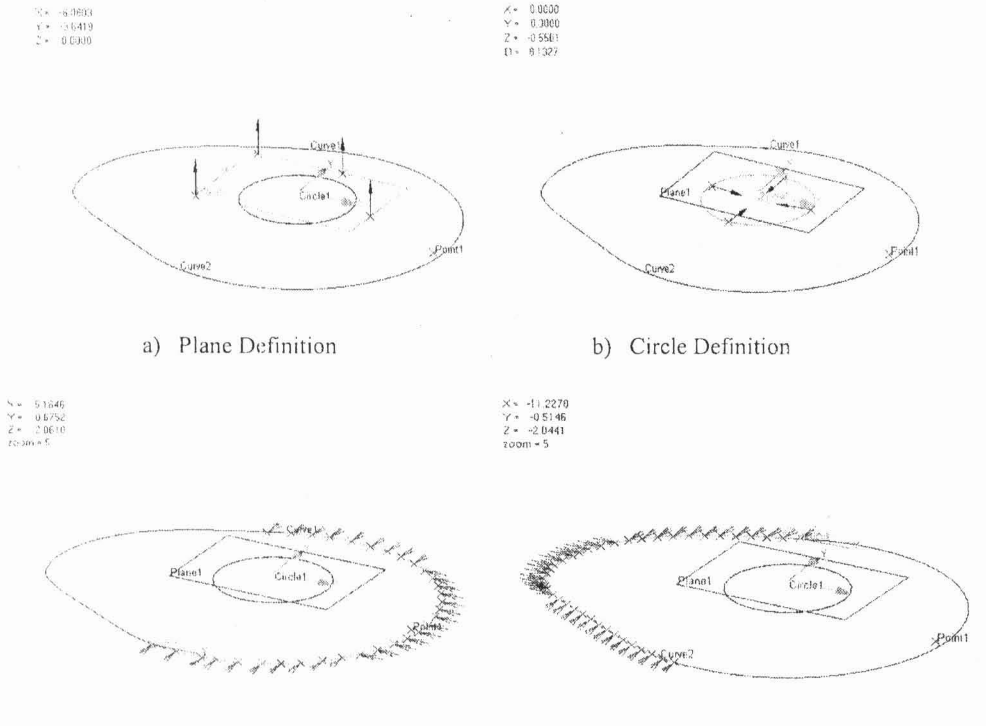
Fig. 4: Computer Numerical Control (CNC) Wire cut Electro Discharge Machine (WEDM) in machining cam profile

Results and Discussion

The results obtained are scanning data, modeling with CAD software, generating code with CAM software and EDM part machining.

Scanning Part

Cam profile information in initial cam geometry, polar coordinate of radius and angle were available from scanning process. An initial cam geometry dimension in Figure 5 needs to be modified based on cam polar coordinate radius and angle to complete modeling process. A circle and curve is transform into a global coordinate system is done automatically using reference after reference plane four points touch of reference plane and inner cam circle are detected as shown in Figure 5a) and Figure 5b) respectively. Figures 5c) and 5d) show a circle is automatically scanned using reference point and other cam lobe are recognized by touching the 40 points with probe in same plane. Data points must be change to polar coordinate from rectangular coordinate. Finally the scanning process will produce initial geometry of cam based on two curves to describe a cam profile and the geometry model is saved in iges. Initial graphics exchange specifications (IGES) is a set of protocols for the display and transfer of graphic documents between different computers aided design system (Schodek et al. 2005).



a) Plane Definition

b) Circle Definition

c) Circle curve

d) Lob curve

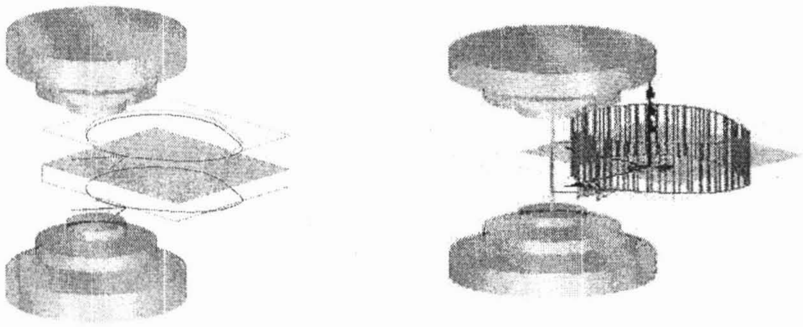
Fig. 5: Initial Result of Scanning Cam Profile

Modeling Cam

CAD modeling software such as Solidworks, Unigraphics, Pro-Engineer and Catia are well known software in solid modeling mode. From scanning process, iges data need a minor modification in order to link 2 curves into single curve of cam profile. However, the transferring model data is lost and only recognized a single circle. It is due to Cimatron cannot identify curve which does not have reference point. Consequently, the data point were used to create overall cam profile curve derived from polar coordinate of scanning process from centre point of a circle. CAD model is saved in drawing interchange format (dxf) format because of WEDM machine only accepted in this format.

Code Generation

Using similar software of CAD, G code for CNC is generated by converting its environment into CAM for wire-cut EDM machine. Figure 6(a) and (b) show the finishing and tool path of WEDM in machining cam. G code generation based on Soddick machine environment in Fikus Wire EDM & Lathe show capabilities of the software in converting appropriate CNC code. Nevertheless, the G code cannot be read by Soddick processor and read according to dxf format of CAD model. Cimatron is suitable for visual inspection of wire tool path generation in cutting steel.

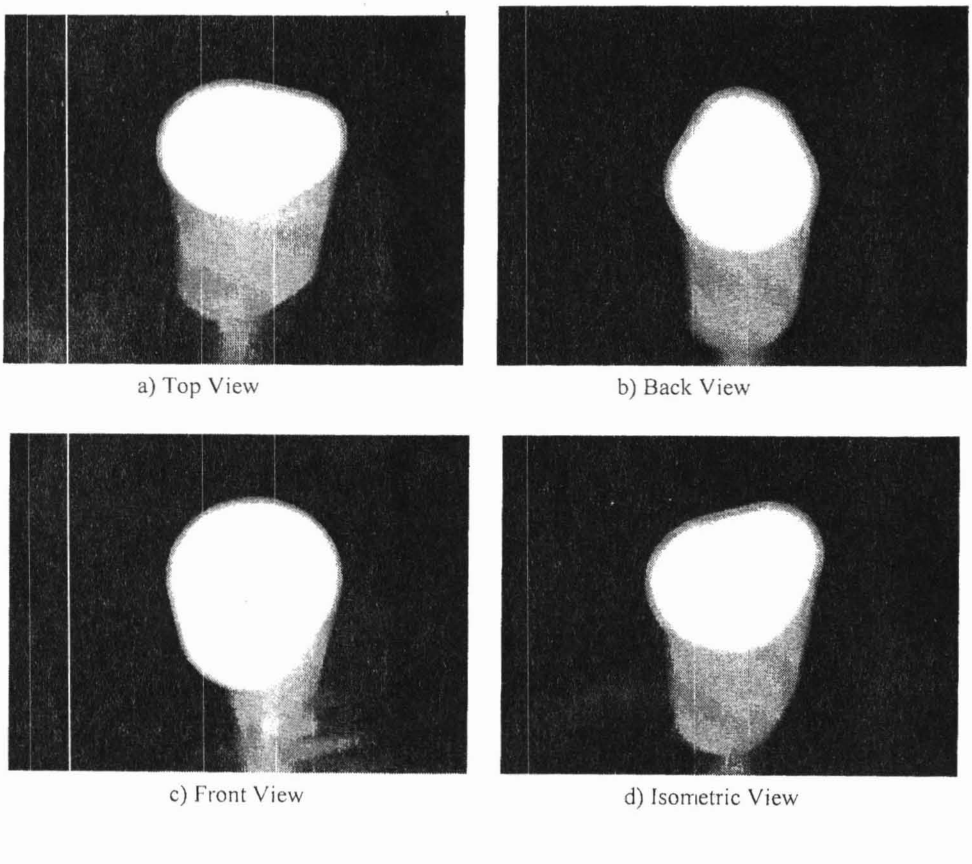


a) Finishing b) Tool Path

Fig. 6: Generating G-code in Fikus Wire EDM & Lathe environment using WEDM CNC

Electro Discharge Machining

Initial cam profile was successfully machined by Sodick CNC WEDM using code generated by the machine from dxf format. Figure 7 illustrates finished cam machining using reverse engineering. The machined cam profile looks similar as well as original cam that can be used in internal combustion engine. The comparison cam geometry between original and reverse engineering cam is shown in Figure 8 which is measured by same CMM. Similar profiles show in cam angle of 0° to 90° before the different increase at the lobe until 180°. Consequently, initial cam can be grinded to achieve similar shape as original cam. The results indicate the reverse engineering approach has capability in developing cam.



a) Top View b) Back View

c) Front View d) Isometric View

Conclusion

The results indicate the reverse engineering approach has capability in developing cam. The scanning process of cam complete in producing cam initial model and data of scanning using CMM and Calypso software. Fikus EDM and Lathe software successfully in generating tool path planning for CNC wire cut EDM. Soddick CNC wire-cut EDM machine cam profile in roughing and finishing sequence.

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