Int. J. Mech. Eng. & Rob. Res. 2014

International Journal of Mechanical Engineering and Robotics Research

ISSN 2278 – 0149 www.ijmerr.com
Vol. 3, No. 4, October 2014

Research Paper

STRUCTURAL ANALYSIS AND MANUFACTURING PROCESS OPTIMIZATION OF AN AEROSPACE COMPONENT

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The aerospace component used in this project is a piston ring which is used in rockets. These piston rings are used to release the rocket due to the pressure release in the chamber. These piston rings are in circular-shape that forms the movable seal in a cylinder. The explosive force of combustion is exerted upon the surface of the piston ring. Due to this force the ring deforms and stresses will be created. In this project 3D model of the piston ring and finite element analysis shall be done to observe the deflections and stresses on the piston ring. From the analysis results high stress locations shall be identified and changes shall be made to reduce these stresses. Static and model analysis shall also be carried out on the modified model to find the dynamic behavior of the component. This project also deals with development of manufacturing process plan of piston ring using CAM software (NX 7.5) which is exclusively CAM software used to generate part program by feeding the geometry of the component and defining the proper tool path and thus transferring the generated part program to the required CNC machine with the help of DNC lines. The operator thus executes the program with suitable requirements. In this project two different manufacturing process plans shall be developed using NX-CAM software and the optimum process plan shall be determined which has less machining time and more surface finish..

Keywords: NX-CAD, Static analysis, Model analysis, NX-CAM

INTRODUCTION

The aerospace component used in this project is a piston ring which is used in rockets. These piston rings are used to release the rocket due to the pressure release in the chamber. These piston rings are in circular-shape that forms the movable seal in a cylinder. Due to experiences from caution and mythical, the structural design was considered the most important design aspect of the project. A static analysis is one of crucial design procedures of a missile piston. The Piston should be studied to withstand and operate under pressure developed in the

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combustion chamber.

Figure 1: Internal Skeleton of the Two Stage of Missile

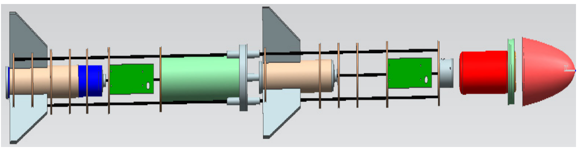
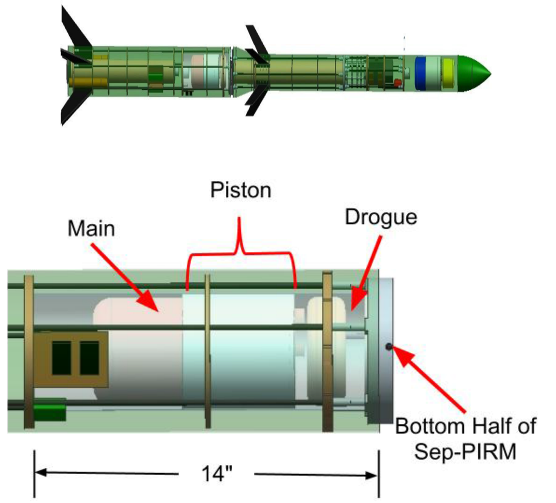


Figure 2: Overall design and Location of the Piston Unigraphics Introduction



NX is one of the world's most advanced and tightly integrated CAD/CAM/CAE product development solutions. Spanning the entire range of product development, NX delivers immense value to enterprises of all sizes. It simplifies complex product designs, thus speeding up the process of introducing products to the market.

The NX software integrates knowledge-based principles, industrial design, geometric modeling, advanced analysis, graphic simulation, and concurrent engineering. The software has powerful hybrid modeling capabilities by integrating constraint-based feature modeling and explicit geometric modeling. In addition to modeling standard geometry parts, it allows the user to design complex free-form shapes such as airfoils and manifolds. It also merges solid and surface modeling techniques into one powerful tool set. Our previous efforts to prepare the NX self-guiding tutorial were funded by the National Science Foundation's Advanced Technological Education Program and by the Partners of the Advancement of Collaborative Engineering Education (PACE) program.

NX is a premier 3D computer aided design suite. It allows you to model solid components and assemblies, to perform engineering analyses such as mechanism simulation and stress analysis, to create tool paths for computer-based manufacturing processes and to perform numerous other engineering design activities in a single software environment. Software suites like NX are referred to as product lifecycle management (PLM).

The NX software integrates knowledge-based principles, industrial design, geometric modeling, advanced analysis, graphic simulation, and concurrent engineering. The software has powerful hybrid modeling capabilities by integrating constraint-based feature modeling and explicit geometric modeling.

It is used, among other tasks, for:

- Design (parametric and direct solid/ surface modeling)
- Engineering analysis (static, dynamic, electro-magnetic, thermal, using the Finite Element Method, and fluid using the finite volume method).

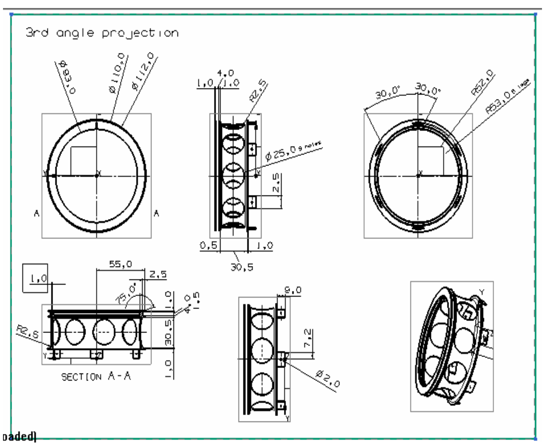
- Manufacturing finished design by using included machining modules

First release of the new "Next Generation" version of Unigraphics and I-deas, called NX. This will eventually bring the functionality and capabilities of both Unigraphics and I-DEAS together into a single consolidated product.

Increasing complexity of products, development processes and design teams is challenging companies to find new tools and methods to deliver greater innovation and higher quality at lower cost. Leading-edge technology from Siemens PLM software delivers greater power for today's design challenge. From innovative Synchronous Technology that unites parametric and history-free modeling, to NX Active Mockup for multi-CAD assembly design, NX delivers breakthrough technology that sets new standards for speed, performance, and ease of use.

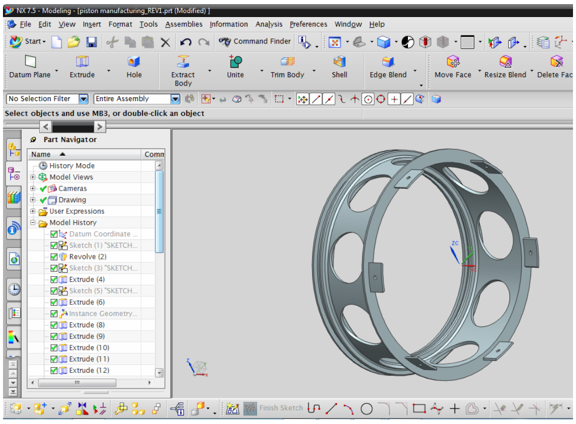
2D input of missile piston

Figure 3: 2D Input of Missile Piston



3D model is designed by using NX cad software.

Figure 4: 3D Modeling of Missile Pistion



Methodology used in the project:

- Develop a 3D model from the available 2D drawings of the piston.
- The 3D model is created using UNIGRAPHICS-NX software.
- The 3D model is converted into parasolid and imported into ANSYS to do static analysis by applying the pressure.
- Calculate stresses and deflections of the original model and check if the component is withstanding for the operating pressure.
- Increase thickness of the piston wall and perform static analysis to observe stresses and deflections on the modified model.
- Perform modal analysis on the modified model to calculate the first 10 natural frequencies to understand the dynamic response of the component

FINITE ELEMENT ANALYSIS OF A MISSILE PISTON

Element Type Used

Element Type: Shell 63

Element Shape: quadrilateral

Number of nodes: 6

Number of DOF=6(Ux, Uy, Uz, RotX, RotY, RotZ)

Physical Properties of Aluminium 6061 Alloy

Density: 2.7 g/cm3

Melting Point: Approx 580°C

Modulus of Elasticity: 70-80 GPa

Poisson's Ratio: 0.33

Yield strength: 180Mpa

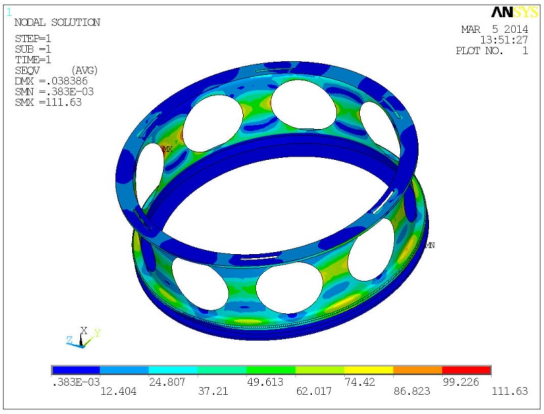
Static analysis for Case 1: In this case1 the thickness of the missile piston was taken as 1mm.The steady state chamber pressure of 6Mpa is applied on the walls. The circumference of the piston was constrained in the radial direction and the bolt locations are constrained in all DOF. The boundary conditions and loading applied on the missile piston is shown below.

Bolt locations constrained in all DOF

Circumference constrained in radial direction

Figure 5: Boundary Conditions Applied on Missile Piston

Figure 6: VonMises Stress on Missile Piston Wall for Case1 Model



From the above results the maximum VonMises stress observed on the piston wall is 111Mpa.The yield strength of the material is 180Mpa.The VonMises stress is less than the yield strength. It can be concluded that the missile piston with 1.5mm thickness is safe for the operating pressure.

Results of Modal Analysis for Case1 Model

From the analysis first 10 natural frequencies are calculated. The same are tabulated below.

Table 1: Analysis of First Ten Natural Frequencies for Case1 Model

Mode No.	Frequency (Hz)
1	9564.7
2	9994.2
3	10261
4	10587
5	11244
6	11374
7	11759
8	12113
9	12179
10	14271

Results of Modal Analysis for Case2 Model

From the analysis first 10 natural frequencies are calculated for case2 model. The same are tabulated below.

Table 2: Analysis of First Ten Natural Frequencies for Case 2 Model

Mode No.	Frequency (Hz)
1	15825
2	16167
3	17314
4	18024
5	20119
6	20191
7	20482
8	20963
9	21682
10	21744

COMPUTER AIDED MANUFACTURING

From the above two static and modal analysis it is concluded that the missile piston case2 model with 1.5mm wall thickness is safe for the operating conditions and therefore it can be sent for manufacturing on MORI SEIKI 4-AXIS CNC turning machine. The main objective of the project is to optimize the manufacturing process plan.

Methodology used in manufacturing of missile piston is mentioned below:

- Identifying suitable machine.
- Selecting suitable tools for manufacturing thin walled component.
- Listing down the Sequence of operations performed on missile piston.
- Generating tool path at specified cutting speed.

IDENTIFY SUITABLE MACHINE

Figure 7: 4-axis CNC MORI SIEKI Turning Machine

SELECTING SUITABLE TOOLS

OD_80_L facing

Facing in the context of turning work involves moving the cutting tool at right angles to the axis of rotation of the rotating workpiece.

OD_80_L rough

This process, also called rough or cutoff, is used to create deep grooves which will remove a completed or part-complete component from its parent stock.

OD_55_L finish

Finish tool remove the left over stock after roughing process. It is the last process which gives surface finish.

ID_80_L rough

Rough tool used to create deep grooves which will remove a completed or part-complete component from its parent stock internally.

ID_55_L finish

Finish tool remove internally the left over stock after roughing process. It is the last process which gives surface finish.

Sequence of Operations Performed On Missile Piston Component

Turning Operations

1. Rough_Turn_OD
2. Finish_Turn_OD
3. Groove_OD
4. Rough_Bore_ID
5. Groove_ID

Milling Operations

1. Drilling_D2
2. Drilling_D19
3. Planar_Mill

maintaining speed 1500rpm and feed 0.24mmpr

Some of the tool path generated images

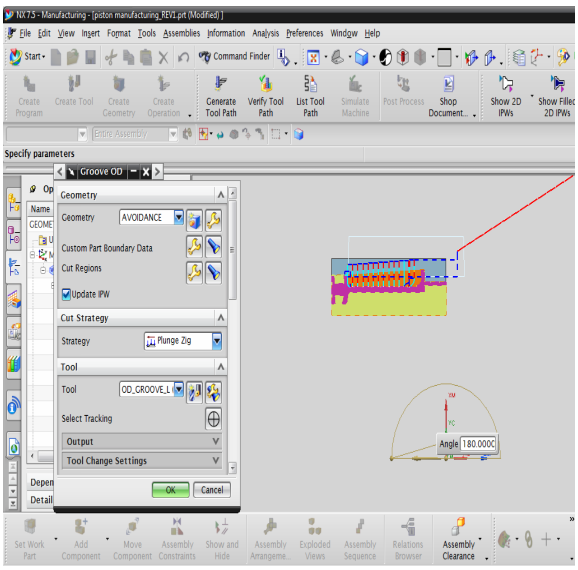


Figure 8: Groove OD Operation

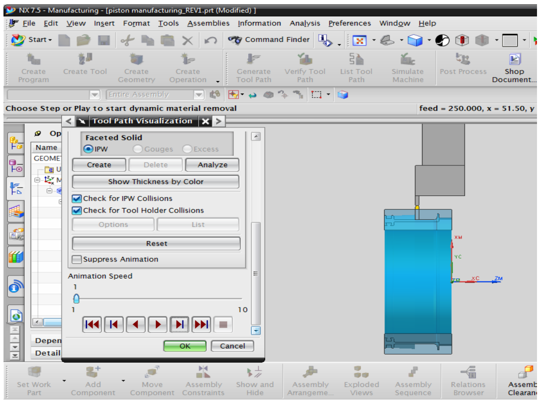


Figure 9: Groove OD Tool Path Verification

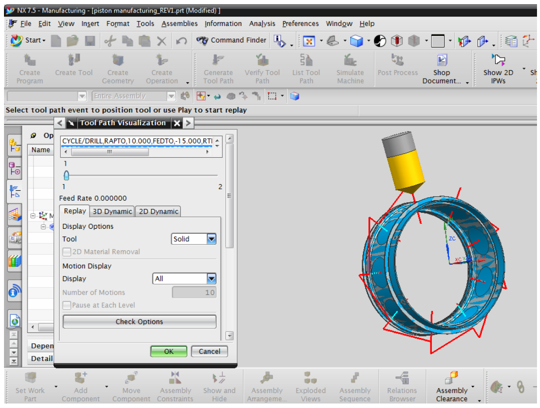


Figure 10: Drilling operation

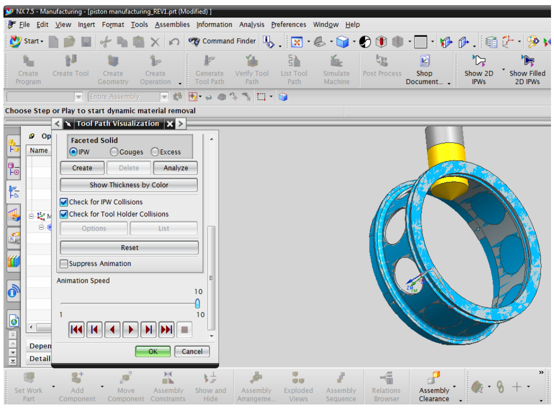


Figure 11: Drilling Tool Path Verification

Operation List by Program

Table 3: OD Operations

OPERATION NAME	OPERATION DESCRIPTION	TOOL NAME
ROUGH_ TURN_OD	turning/ ROUGH_TURN_OD	OD_80_L
FINISH_ TURN_OD	turning/ FINISH_TURN_OD	OD_55_L
GROOVE_OD	turning GROOVE_OD	OD_GROOVE_L
GROOVE_OD_1	turning/ GROOVE_OD	OD_GROOVE_L

Table 4: Internal Operations

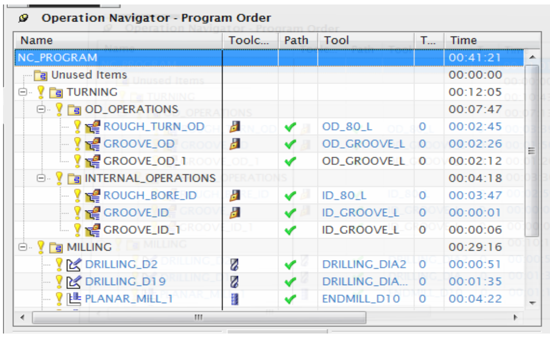
OPERATION NAME	OPERATION DESCRIPTION	TOOL NAME
ROUGH_ BORE_ID	turning/ROUGH_ BORE_ID	ID_80_L
GROOVE_ID	turning/ GROOVE_ID	ID_GROOVE_L
GROOVE_ID_1	turning/G ROOVE_ID	ID_GROOVE_L

MANUFACTURING PROCESS OF PISTON ON CNC MACHINE

- Raw material is placed on the machine, and degree of freedom is arrested using fixtures.
- The raw material is loaded on the turning machine. ID & OD operations and grooving operations are done on the raw material.
- After completing turning operations the semi finished component is loaded on the horizontal mill machine for drilling operations.
- After completing drilling operations this semi finished component is loaded on the vertical mill machine for planar mill operation.

The time taken by piston component for manufacture on tuning, horizontal mill and vertical mill machines is 41m.

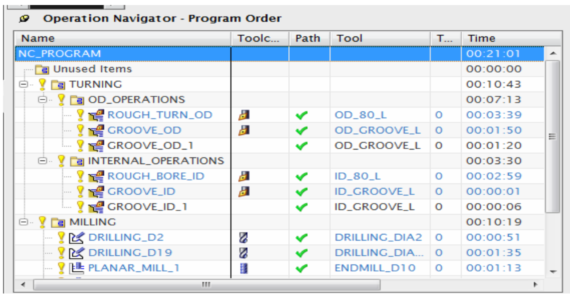
Figure 12: Manufacturing Time Manufacturing Process Planning Using Turning-mill Machine



- Raw material is placed on the machine, and degree of freedom is arrested using fixtures.
- The raw material is loaded on the turn-mill machine. ID & OD operations and grooving operations are done as well as milling operations also done on the raw material because it is 4-axis turn-mill machine and it is capable to do milling operations and drilling operations.

The time taken by piston component for manufacture on tuning-mill machines is 21m.

Figure 13: Optimized Manufacturing Time



RESULTS DISCUSSION

There is no requirement for jig in turn mill machine component is hold in fixture and drilling operations is performed. Where as in CNC machine Raw material is placed on the machine, and degree of freedom is arrested using fixtures. After completing drilling operations this semi finished component is loaded on the vertical mill machine for planar mill operation.

MANUFACTURING OF PISTON ON 3-AXIS MACHINES

Values taken when components is manufactured on machines

Time and cost calculation for manufacturing piston as shown below including setup time and manual modification of NC program on CNC machine.

Raw material cost of piston aluminum alloy 6061 with dia 115mm length 55mm = 990rs

Manufacturing time taken by single component= 41min

Machining cost per hour for milling operations = 1200rs

Machining cost per hour for turning operations = 800rs

Machining cost per piece for vertical milling operations (machining cost per min x machining time in min) = 1200/60*15min= 300rs

Machining cost per piece for horizotal milling operations (machining cost per min x machining time in min) = 1200/60*18min= 360rs

Machining cost per piece for turning operations (machining cost per min x machining time in min) = 800/60*8min= 107rs

Manufacturing cost of the jig (Jig is used for drilling holes on horizontal milling machine) = 467rs

Total machining cost per piece= vertical milling + horizontal milling +turning= 300+360+107 = 767rs

Direct Labour Cost = Tm * Man Hour Rate Rs.

Man Hour Rate = 500 Rs.

Tm = 41/60 hours= 0.6833 hrs

Direct Labour Cost = 341 Rs

Table 5: Turning, Horizontal & Vertical Milling SETUP

SET UP	TIME RE-QUIRED IN MINS.	MACHINING COST PER HOUR	MACHINING COST/PIECE
TURNING	08	RS.800/HR	RS.107
VERTICAL MILL	15	RS.1200/HR	RS.300
HORIZONTAL MILL	18	RS.1200/HR	RS.360
TOTAL	41		RS.767

Total cost of the component manufacturing on turn mill machine =

Raw material + manufacturing + jig (including machining time and raw material) + labour cost = 990+767+ 1791+341= 3889 rs.

MANUFACTURING OF PISTON COMPONENT ON TURN MILL MACHINE

There is no requirement for jig in turn mill machine component is hold in fixture and drilling operations is performed.

Machining cost per piece for turning

operations (machining cost per min x machining time in min) = 1000/60*21min= 350rs

Direct Labour Cost = Tm * Man Hour Rate Rs.

Man Hour Rate = 500 Rs.

Tm = 21/60 hours= 0.35hrs

Direct Labour Cost = 175 Rs

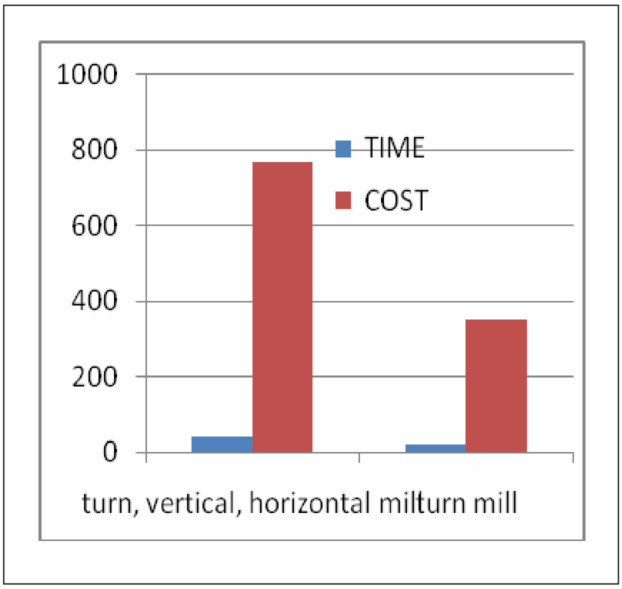
Table 6: New Setup on Turn Mill

SET UP	TIME REQUIRED IN MINS.	MACHINING COST	MACHINING COST/PIECE
TURN MILL	21	RS.1000/HR	350
TOTAL	21		350

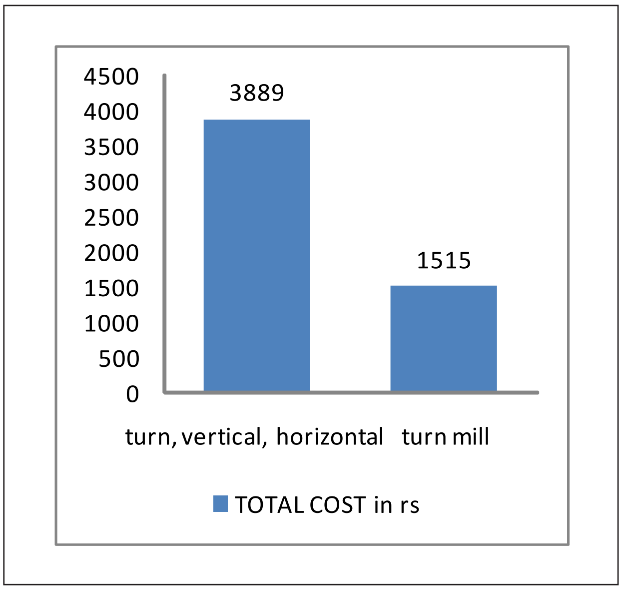
Total cost of the component manufacturing on turn mill machine =

raw material + manufacturing + labour cost = 990+350+175= 1515rs.

GRAPH



Graphical representation of total cost including raw material and labour cost.



CONCLUSION

Missile piston is modeled using unigraphics software NX_CAD. A static analysis was carried out by applying the pressures (6Mpa) developed from the combustion chamber. Two different iterations were done initially by considering the wall thickness as 1mm and later by 1.5mm. The maximum VonMises stress observed on the piston wall is 585Mpa. The yield strength of the material is 180Mpa. The VonMises stress is more than the yield strength so the component is not safe at the operating pressure. So the thickness of the piston wall is increased to 1.5 mm. Maximum VonMises stress observed on the piston wall is 111Mpa.The yield strength of the material is 180Mpa. The VonMises stress is less than the yield strength. It can be concluded that the missile piston with 1.5mm thickness is safe for the operating pressure. Modal analysis also done on the piston to determine the natural frequencies and mode shapes of a structure. From the above finite element analysis it is concluded that case2 model has better dynamic response when compared to case1. Finally case- 2 model that is 1.5 mm thickness model is manufactured.NC program is generated using unigraphics software NX_CAM. Optimized process plan for manufacturing piston component in turn mill machine and it is graphically represented in results. Graphical representation of product cost and time are shown in results. The total time required for the manufacturing of the component is reduced. The production cost of the product is also reduced.

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