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Strategic Justification of Advanced Manufacturing Technologies Through Manufacturing Technology Research

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Abstract— **Advanced Manufacturing Technologies (AMTs) have been helping manufacturing companies in the 21st Century to successfully manage the unpredictable, high-frequency market changes driven by global competition. However, despite the overwhelming evidence of the AMTs contribution to companies' responsiveness to all the current global market changes, the relatively high cost of AMTs has made companies in developing economies reluctant to adopt AMTs. Research has nonetheless shown that adoption of more of the AMTs by companies in developing economies can be achieved with appropriate justification approaches and criteria. This paper summarizes the objectives and principal findings of two research projects undertaken to provide strategic justification of AMTs. The first project was concerned with widening the capability of a 3-Axis Computer Numerical Control (CNC) Vertical Machining Centre (VMC) to include turning operations as well. The most suitable programming operations for the included turning operations were found to be drilling and boring cycles. The second project was concerned with the production of a collimator, a complex water-cooled frontal electrode used on the plasma-arc torch that requires precision machining to achieve its functionality, by applying the adaptations made to the 3-Axis CNC VMC in the first project. The produced collimator assembly was inspected for dimensional accuracy and surface finish and tested on a plasma-arc torch testing rig by a user mining company. The final product was found to meet the required specifications. The research projects demonstrated that by simple adaptations, a relatively cheap 3-Axes CNC VMC can perform much more operations consequently making the investment attractive.**

Keywords*— *Advanced Manufacturing Technology (AMT), CAD/CAM, Computer Numerical Control (CNC), Strategic Justification, Vertical Machining Centre (VMC)

I. INTRODUCTION

The manufacturing sector is recognized [1, 2] as the sector that has a larger economic multiplier than any other sector due to its pivotal role as a source of high-value jobs within an economy, and its essential function within a national innovation system. It is, therefore, imperative that local companies in the sector stay competitive if they have to provide a competitive advantage to any nation in today's globalized world. Globalization has led to the international distribution of value chains and dynamic competition thereto. Leading manufacturing economies have invested considerable efforts into understanding how value-addition can be organized [3–5] and pursued within national manufacturing systems to ensure firms compete effectively in the global economy, including potential for gaining competitive advantage from new strategies and technologies. Noting that manufacturing has evolved from a more labor-intensive set of mechanical processes (traditional manufacturing) to a sophisticated set of information-technology-based processes (advanced manufacturing), only firms that possess Advanced Manufacturing Technologies (AMTs) have the potential of being competitive.

AMTs such as computer-aided design (CAD), computer-aided process planning (CAPP), computer numerical control (CNC) machines, flexible manufacturing cells/systems (FMC/FMS), and computer-integrated manufacturing (CIM) provide adopting companies with the potential to, among other things, gain earlier entrance to market, respond more quickly to changing customer needs and offer higher quality products with improved consistency and reliability [6]. AMTs are used to revise completely the capability of manufacturing, improve manufacturing parameters and ultimately the company's order winning criteria that include cost reduction (more efficient processes through the better use of inputs such as raw materials, direct labor and energy), increased flexibility, and product quality [7]. AMTs thus provide adopting companies with the ability to successfully manage the unpredictable, high-frequency market changes driven by global competition. Clearly, to enhance industrial competitiveness in developing countries like Zambia, manufacturing companies must adopt AMTs. Unfortunately, the levels of advanced manufacturing technologies in Zambian manufacturing companies is very low [8].

AMTs operate in two powerful ways to affect competitiveness; firstly, by changing the price structure, and secondly, through its impact on non-price factors, that might include design and marketing related, production related,

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finance related and quality related factors [7]. It is becoming clear that whilst price factors remain an important determinant of competitiveness, non-price factors are having a major impact on world markets. Whereas the diffusion of previous generations of technologies was heavily influenced by the need to lower labor costs, the advantage of AMTs is their ability to provide increased flexibility in terms of reduction in the cost of working capital, increases in the responsiveness of delivery, lower rates of rework and scrap, and the ability to increase the customization of the products [7]. Labor that previously appeared on the cost side now is seen as a vital resource. Thus, the decision for the adoption of AMT apart from its likely impact on unit costs must take into consideration the above factors that are much more difficult to measure [7].

Strategic needs cited as the justification for AMT investment include competitive positioning, manufacturing capabilities, and learning [9]. The strategic planning approach takes a long-term comprehensive view of both business and technology issues. Companies should first identify the range of products/markets that are likely to be manufactured. In seeking to match products with technologies, management should be aware that adoption of AMTs could bestow not only operational benefits such as improved quality, increased efficiency and shorter lead times but marketing and strategic advantages as well [7]. Reference [10] added that benefits such as increased market share, reduced prices, improved responsiveness to changes in the marketplace, the ability to offer a continuous stream of customized products, faster product innovation and the improvement of the company's image have all been ascribed to the operation of flexible AMT.

Efficient utilization of advanced manufacturing technology (AMT) is considered as a very important tool for manufacturers worldwide to maintain and strengthen their ability to compete on extremely competitive international markets. Many companies are currently strengthening their competitive positions by updating the technologies used in the manufacturing process [11]. These changes have largely been in response to the increasing need for companies to become competitive not only in terms of cost but also with regard to quality and responsiveness to customers. As their counterparts in developed economies adopt AMTs, manufacturing companies in developing economies increasingly recognize the need to do likewise. Although many of their owners and managers intuitively recognize the strategic benefits of AMT, they are reluctant to make the necessary capital investment. The problem is that AMT projects are usually expensive and as it is rather difficult to estimate its real impact and various company-wide benefits, it is hard to make the relevant decisions whether to invest in such a project [12].

Reference [13], in their study on the investment justification of AMTs, found that justification approaches and criteria preference help to explain the adoption of the most integrated technologies. This is because of the relatively high cost of AMTs and the moderate-to-high risk involved in adopting these technologies [13]. In addition, [7] augments that AMTs decisions should be justified by assessing how manufacturing can give a distinctive competitive edge to the company. Citing [14], [7] points out that the adoption of AMTs gives firms a greater number of growth options to enter new markets and to create new products than firms relying on traditional manufacturing technologies and generic strategies.

Literature on justifying investment in AMT identifies three approaches [11, 12], namely:

i. The economic approach. Involving the classical financial justification techniques of payback period (PP), return on investment (ROI), internal rate of return (IRR), and net present value (NPV).

ii. The strategic approach. Involving analysis of competitive advantage, business objectives, research and development objectives and technical importance.

iii. The analytic approach. Involving value analysis, portfolio analysis and risk analysis (RA).

The strategic justification approaches tend to be less technical than economic and analytic methods, but it should be stressed that they are quite often used in combination. The main advantage of the strategic approaches is their direct linkage to the goals of the company. Criteria such as meeting the business objectives, comparison with competitors, the retention or attainment of competitive advantage and industry leadership might be utilized as suitable factors for the relevant decision-making processes where AMT projects are scrutinized [12].

This paper reports on the two research projects under strategic justification approach.

II. Research Project One: Adaptive Widening of a 3-Axis CNC Vertical Machining Centre to Include Turning Operations

The continuous quest for modernization and industrialization has brought a great challenge for developing countries such as Zambia in that these countries have to keep on importing production machinery whose spares cannot be obtained locally. This problem has been compounded by developing countries' lack of funds to acquire machinery such as CNC machine tools that could produce the much-needed spares. The initial cost of CNC machine tools, though not substantially high for developed countries, is prohibitive to many companies in developing economies such as Zambia. It is, therefore, imperative that avenues of adapting these machines to perform a variety of operations than what they were initially designed for are sought and thereby make the investment much more lucrative. Although various CNC machine builders have developed machines that combine turning and milling operations through the construction of more than three axes of rotation, a 3-axis machining centre has no provision for conversion to a turning centre. It was, therefore, deemed necessary to conduct preliminary investigations into the possibility of modifying a 3-axis CNC Vertical Machining Centre (VMC) to include CNC turning operations. This was the goal of the first research undertaken in the Department of Mechanical Engineering of the School of Engineering at the University of Zambia.

A Supermax 65A VMC with Fanuc control system was used in this preliminary investigation. The main objective was to design fixtures and identify suitable machining cycle so that turning operations could be performed within the machine design parameters and programming software capabilities.

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Fixtures for tool and workpiece holding were designed, manufactured and fitted onto the VMC. These were designed to meet the two basic components for turning operations, which are the spindle for workpiece holding and rotation, and tool-holding mechanism for feeds. Fig. 1 [15] shows basic machining orientations in milling and turning. To achieve the turning operations on the CNC VMC a drilling cycle feature where the workpiece assumed the position of a drilling tool approaching a single fixed point was found to be the most suitable programming operation [16]. In this arrangement, the workpiece and the cutting-tool were swapped; that is, the workpiece was mounted on the machine tool spindle giving it the desired rotation about the machine's Z-axis and a feed along the same axis, while the appropriate turning tool was mounted on the machine bed for movement in the Y-axis only.

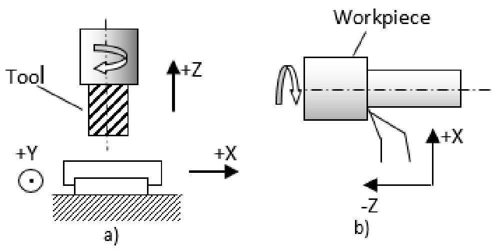


Fig. 1. Machining orientations in: (a) Milling, and (b) Turning.

Mastercam® Mill V7 software used to generate the Numerical Control (NC) file. Mastercam® is an integrated CAD/CAM software package that enables a programmer to make a geometric drawing of the part to be machined, simulate toolpaths and generate the NC file. With the adoption of the workpiece as a 'drilling tool', the requirement for workpiece profile for the generation and definition of NC-toolpaths was not a straightforward case. The main reason was that the 3-axis VMC could only cut in the vertical direction (milling operation in the XY plane) whereas the required tool-plane for the proposed turning operations is either YZ or XZ planes. To overcome this challenge, a reversed operation was simulated where the desired profile was formed by the addition of material to get the final profile as shown in Fig. 2 [16]. While drilling involves removal of the unwanted material from the workpiece to get the required hole, the proposed turning simulation molded the unwanted material into a turned workpiece. For cases of straight turning, movement of the turning tool (Y-axis movement of the table) simulated the depth of cut and movement of the workpiece mounted into the spindle (Z-axis movement) simulated the size of the feed. For formation of chamfers and radii features, this required simultaneous movements of both the tool (machine table) and the workpiece (spindle). The generated program was edited in order to turn the correct profile. The most crucial statements in the program were the tool change and plane cutting. Program editing was done during the backplot feature of the Mastercam® Mill software.

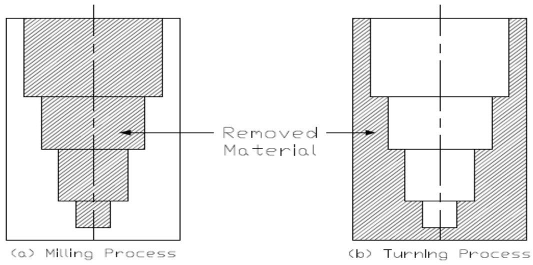


Fig. 2. Simulated material removal for the turning process.

Fig. 3 [16] shows the VMC setup for turning operations. The major difference between the simulated turning programming to the actual operation on the VMC using Mastercam® was in establishing the Zero-Reference-Point [16]. This was the tip-point of the turning tool with respect to the surface coordinates (datum) of the workpiece. In simulated programming, the turning tool-tip was used to establish the Zero-reference point as opposed to the use of the measuring probe [16].

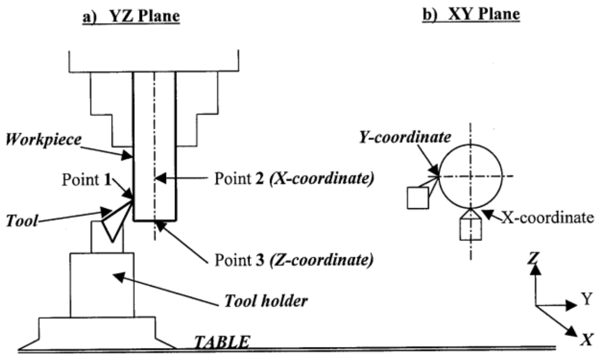
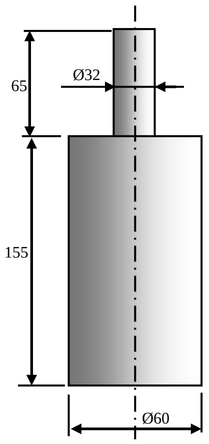


Fig. 3. Establishing Zero-Reference-Point for turning operations on VMC.

During testing, the conventional single point turning tool was unable to completely turn radius in and radius out profiles. Consequently, a multi-profile cutting tool was designed which maintains constant cutting tool geometry as it machines around curved profiles, and it successfully turned the profiles shown in Fig. 4 and 5 [15, 17].



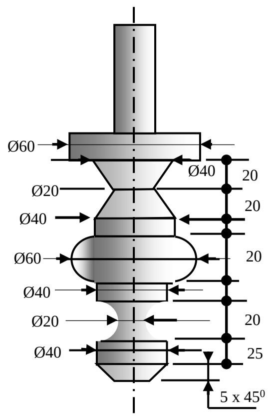


Fig. 4: Workpiece and final product profile.

Fig. 5. Final product profile machined using the designed multi-profile cutting tool.

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III. Research Project Two: Tool Design for the Production of a Collimator on a 3-Axis Vertical Milling Centre

The developed methodology for adapting the Supermax 65A 3-axes CNC VMC to include turning operations was tested and validated by producing a real commercial product with stringent precision requirements. This was the objective of the second research. The product chosen for this exercise was a collimator assembly. The collimator assembly is made up of two separate components, Holder and Insert (shown in Fig. 6 [18]), whose metallurgical composition is between 90 to 99 percent copper. The collimator assembly is a water-cooled frontal electrode used on the plasma arc torch (see Fig. 7 [18]). This torch is used in the reheating of the alloy prior to atomizing. In order to accommodate plasma gas flow, process thermodynamics and to prevent coolant leakages, the collimator components require precision machining that is best performed on CNC lathe machine tools.

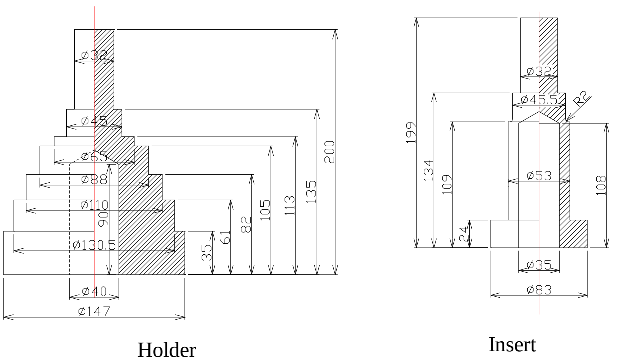

Fig. 6. The Collimator assembly Holder and Insert dimensions.

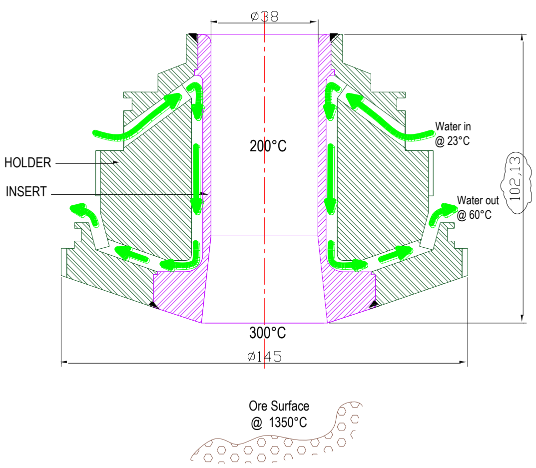

Fig. 7: The Collimator assembly.

During the time this research was undertaken in 2006, a cobalt refinery plant at Chambeshi Metals Plc in Zambia, when running at normal capacity consumed one collimator in every three to four weeks. The cost of replacement of each collimator at that time was approximately US $3,800.00 from Mitutoyo and Fowyer of the USA [19]. Chambeshi Metals Plc noted that it was spending colossal sums of money in importing the collimator and was, therefore, looking at sourcing it locally considering that the component's raw material was locally available. However, local companies failed to achieve the required tolerances using conventional machining and had very little or no capacity to invest in CNC machine tools. This presented an opportunity to demonstrate the flexibility of a 3-Axis CNC VMC, and how manufacturing capability can be achieved.

In this research, the production process was developed, production tools for turning, threading and boring, and workpiece and tool holding mechanisms were designed and manufactured. The different setups used are shown in Fig. 8 and 9 [18]. During programming, instead of generating the NC-file using Mastercam® Mill and then editing the program, a less time-consuming approach was used by modifying the Mastercam® Lathe V9 to generate NC part program to run on the CNC VMC via Direct Numerical Control (DNC). With these techniques, the produced collimator met the specified dimensional accuracy and surface finish. The total cost of producing the collimator came to about ZMK 9,975,686.00 (US $2,216 equivalent) [19].

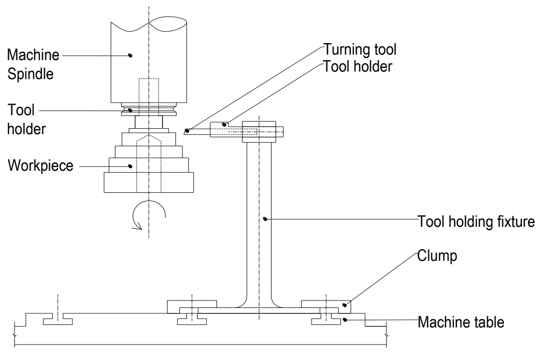

Fig. 8a: Turning setup.

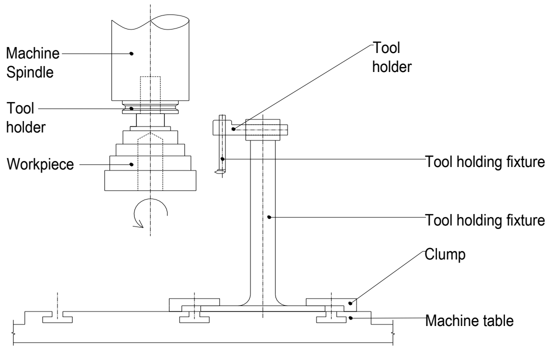

Fig. 8b: Threading setup.

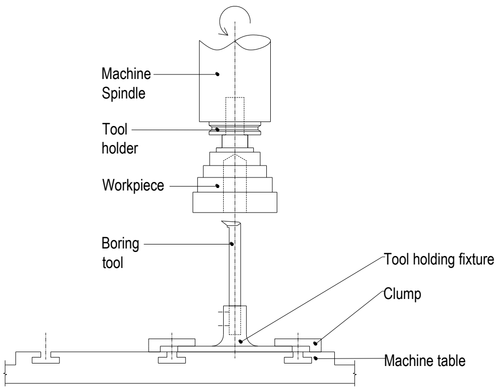

Fig. 9a: Boring setup.

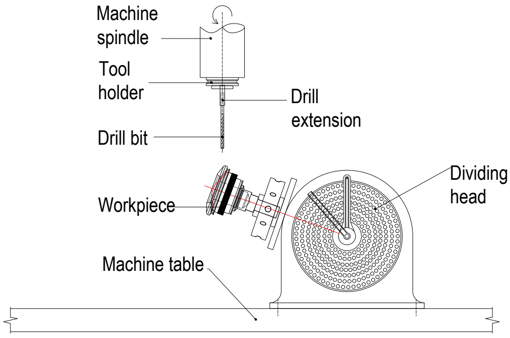

Fig. 9b: Drilling setup.

The produced Collimator assembly, shown in Fig. 10 [18], was further inspected and tested on a plasma arc torch-testing rig at Chambeshi Metals Plc, Smelter Plant. The site tests were meant to check whether the produced Collimator assembly would fit in the plasma arc torch and operate without any defects. The first part of the site tests involved physical inspection of the following parameters: 1) dimensions; 2) weight, 3) 'O' rings, 4) coolant passages and 5) visual inspection. Results were satisfactory.

Fig. 10: Collimator assembly produced using the 3-Axis Supermax CNC VMC.

Having been satisfied with the physical inspection, the Collimator assembly was mounted on the Plasma arc torch testing rig and pressure tested on water as well as the arc. After testing, the results showed that the arcing surface on the collimator had been unaffected. This implied that the temperature, as well as the electrical conductivity of the material from which the collimator was produced, were satisfactory. However, there was water leakage encountered during pressure tests on the plasma arc testing, which was due to poor welding of copper-based materials using the available welding machines in the University workshops at that time, resulting in failure to achieve a good watertight weld [18].

IV. CONCLUSION

The reported projects provide the qualitative benefits of manufacturing technology research in extending the capabilities of 3-axis VMC, which would lead to the full realization of the benefits an investment in such technology can bring to a company. It must, however, be noted that the methodology that was used to demonstrate the ability to extend the utilization of the VMC is not as simple as the acquisition of new technologies alone. To achieve the desired benefits, there must be corresponding practices to improve human resource ability and skills in the new technology to ensure that the implementation of technologies leads to the expected benefits [20–23].

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