A FEASIBILITY STUDY ON IMPLEMENTING AGILE MANUFACTURING IN A PUMP MANUFACTURING INDUSTRY

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Abstract - *Due to the absence of agile characteristics, many traditional products have been struggling to face the onslaught of intensive competition. Agile characteristics would enable a product to be reconfigured quickly in response to the customers' dynamic demands. One of the theoretical propositions is that, computer-aided design (CAD)/computer-aided manufacturing (CAM) technology possesses the capabilities to infuse agile characteristics in the traditional products. To examine this theoretical proposition, the research work being reported in this paper was carried out. During this research, the pump was chosen as a candidate of traditional product. The impeller and casing of the pump were subsequently modelled using CAD technology and design equations. Subsequently, four impeller and casing models were evolved. To examine the manufacturing aspect of these models, CAM technology was used. This research outcome indicated the feasibility of converting a traditional product into an agile compatible product using CAD/CAM technology.*

Keywords: Agile manufacturing, Computer-Aided Design, Computer-Aided Manufacturing, Pump Design, Product Design, Product Development.

1. INTRODUCTION

Agile manufacturing can be defined as the capability of surviving and prospering in a competitive environment of continuous and unpredictable change by reacting quickly and electively to changing markets, driven by customer-designed products and services.

Agile manufacturing is a new expression that issued to represent the ability of a producer of goods and services to thrive in the face of continuous change. These changes can occur in markets, in technologies, in business relationships and in all facets of the business enterprise. Agile manufacturing requires to meet the changing market requirements by suitable alliances based on core-competencies, organizing to manage change and uncertainty, and leveraging people and information.

Agile manufacturing is a vision of manufacturing that is a natural development from the original concept of &lean manufacturing'. This requirement for manufacturing to be able to respond to unique demands moves the balance back to the situation prior to the introduction of lean production, where manufacturing had to respond to whatever pressures were imposed on it, with the risks to cost and quality. The move to lean production from agile and vice versa is a major challenging task.

The main objective of this particular classification is to develop a suitable framework for AMSs along these four dimensions/criteria. Achieving agility therefore requires flexibility and responsiveness in strategies, technologies, people and systems. Table 1 shows the classification of the literature on AM and the corresponding references on the basis of strategies, technologies, systems and people.

Table 1: Classification Of Agile Manufacturing Literature

Criteria for classification of the literature	Sub-classification
Strategies	Virtual enterprise Supply chain Concurrent engineering
Technologies	Hardware –tools and equipments Information technologies
Systems	Design systems Production planning and control systems System integration and database management
People	Knowledge workers Top management support and employee empowerment Training and education

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1.1. A FRAMEWORK FOR THE DESIGN OF AGILE MANUFACTURING SYSTEMS

This development is based on the literature survey and its analysis. It can be seen that most of the literature on AM and related issues either deal with strategies or techniques, but not an integrated view of developing an AMS. In this section, an attempt has been made to present an integrated strategic and techniques framework for the design and development of AMSs together with people and systems issues. Agile manufacturing can successfully be accomplished using various well-defined agile system architectures. The system architecture for AM may include control, function, process, information, communication, distribution, development, and implementation.

Effective and efficient implementations of AMSs require enterprise level integration. The first step in this direction is to integrate design, process planning and scheduling. A bidding-based approach to the integration of computer-aided design, process planning and real time scheduling can be used for the design and implementation of AMS.

Each machine has its own process planner and responds to the product's request in a way that is consistent with its capabilities and capacities. When more than one machine offers certain process(es) for the same requirements, they enter into negotiation. Based on processing time, due date and cost, one of the machines wins the contract. The successful machine updates its schedule and advises the product to request raw material for processing. The concept was implemented using a multi-agent system in an object-oriented programming language. The task of decomposition and planning are achieved through contract nets. As discussed earlier, Internet plays a significant role in AMSs.

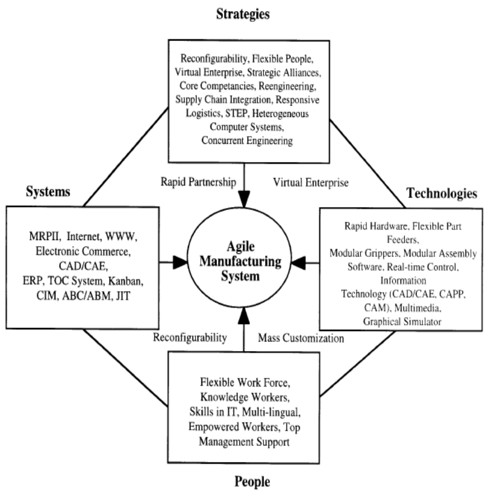

Fig - 1: A Framework for the Design of Agile Manufacturing Systems

The product is represented in a STEP model with detailed design and administrative information including design specifications, batch size, and due dates. Upon arrival at the manufacturing facility, the product is registered in the shop floor manager which is essentially a coordinating agent. The shop floor manager broadcasts the product's requirements to the machines. The shop contains autonomous machines that have knowledge about their functionality, capabilities, tooling and schedules.

Based on the literature survey, a conceptual model for the development of AMSs is developed as shown in Fig. 1. As indicated earlier, the model has been developed along four key dimensions including strategies, technology, people and systems. The main objective here is to develop integrated AMSs with the help of suitable strategies and techniques to develop rapid partnership formation, VE and reconfigurability for mass customization. Further details of the model are discussed hereunder.

2. METHODOLOGY

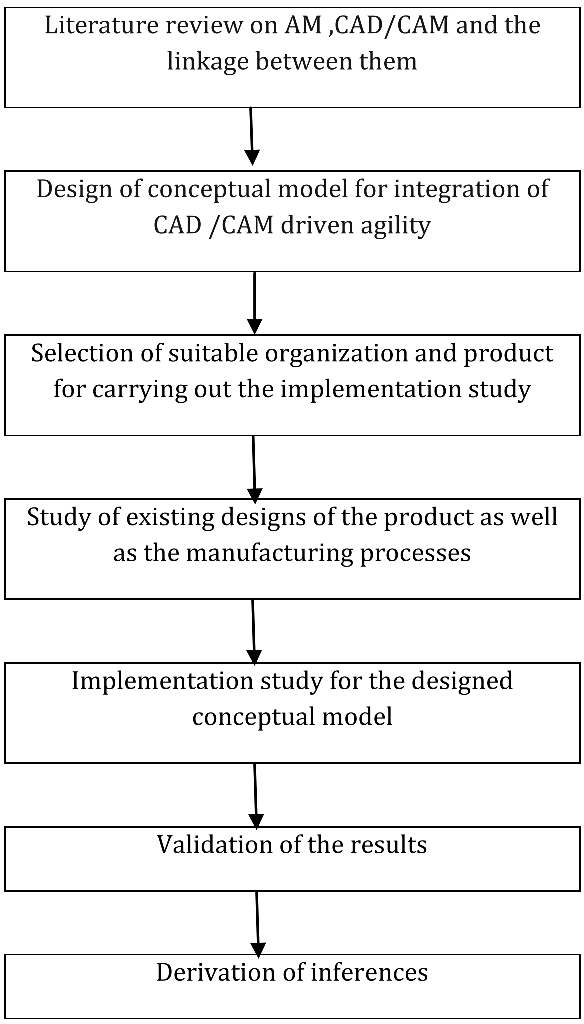

Fig - 2: Methodology

The literature was reviewed from the perspectives of AM, CAD/CAM and the linkage between them. Then, the conceptual model has been designed based on the literature review. This is followed by the selection of a suitable manufacturing organization as well as the product for carrying out the implementation study. After identifying the suitable manufacturing Organization, the existing products manufactured as well as the manufacturing processes employed were studied.

Then the deployment of the designed conceptual model has been done according to the various phases being planned. This is followed by gathering the feedback of the experts regarding the outputs generated out of the implementation study. This is followed by the derivation of inferences based on the implementation study experiences.

2.1. DESIGN OF CONCEPTUAL MODEL

The designed conceptual model is shown in Figure 3. The motivation behind the development of conceptual model is that it acts as technology-integrated product design and development cycle enabling the rapid design and development of products. As shown, the customers' varied requirements will be collected in the form of varied product specifications. Once the product specifications have been finalized, the digital versions of those specifications will be developed using CAD technology.

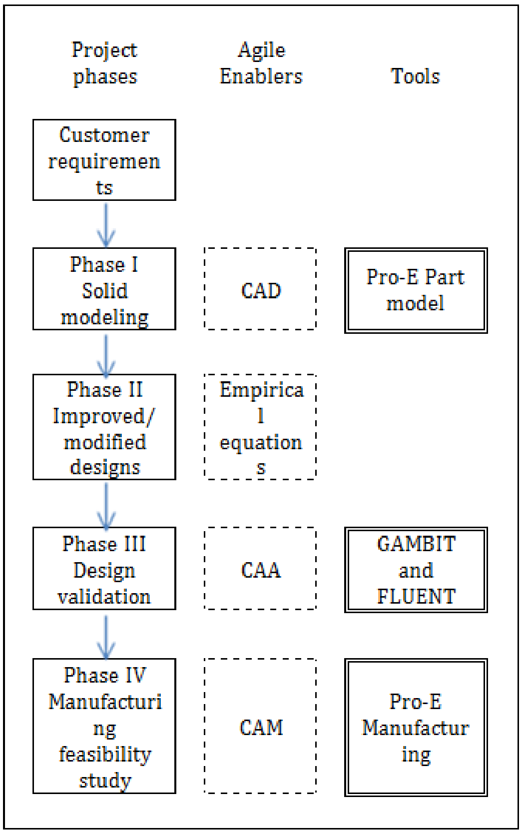

Fig - 3: Design of Conceptual Model

The design modifications or new product designs are made using innovation integrated tools. Sometimes the usage of the empirical relations also could be employed. Then the new designs are practically validated using CAA software packages. The manufacturing feasibility of the developed designs will be carried out using CAM software package.

3. IMPLEMENTATION STUDY

The implementation study has been carried out in a pump manufacturing organization located in Coimbatore, Tamil Nadu, India.

3.1. ABOUT COMPANY AND PRODUCTS

The name of the company is 'JAY Pumps'. The company has more than 10 numbers of employees. The current turnover of the company is INR 1,000,000. The number of employees currently working in the company is 16. The products manufactured by the company include self-priming pumps and centrifugal pumps. There existed a need for the case organization to develop new products thereby enabling agility in product design and development which motivated to conduct this study.

3.2. CAD MODELING OF EXISTING IMPELLER AND CASING DESIGNS (PHASE I)

After studying the existing designs and collecting the 2D drawings from the company, the CAD models of the existing impeller and casing designs have been created using Pro-E.

Fig - 4: Casing

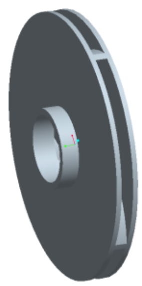

Fig - 5: Impeller

3.3. DEVELOPMENT OF NEW IMPELLER DESIGNS (PHASE II)

The existing design is depicted as 'X' whereas the proposed designs are depicted as Y1, Y2, Y3 and Y4. The design code, head, discharge values, number of vanes and design criteria used. Keeping the existing impeller design as reference, the new impeller designs were generated using the empirical equations.

Step 1: **Calculation of specific speed**

Specific speed

$$N_s = \frac{N\sqrt{Q(gpm)}}{H^{\frac{3}{4}}\,(ft)}$$

$$= \frac{2800\sqrt{52.265}}{51.02^{3/4}}$$

=1060.4rpm

From Figure 7, the efficiency of this pump for *Ns* = 1,060.4 rpm and *Q* = 52.265 has been found to be 57.5%.

Step 2: **Calculation of outside diameter**

Outside tip speed

$$U_2 = \left(\frac{H}{\eta}\frac{g}{\Psi}\right)^{\frac{1}{2}}$$

$$= \left(\frac{15.55 \times 9.81}{0.575 \times 0.6}\right)^{\frac{1}{2}}$$

=21.03m sec^{-1}

Angular velocity

$$\omega = \frac{2\pi N}{60}$$

$$= \frac{2\pi \times 2{,}800}{60}$$

= 293.22rad sec^{-1}

Table – 3: Specifications of the Existing and Proposed Impeller Designs

Design code	Head (m)	Discharge (lps)	Number of vanes	Shaft power (HP)
X	15.55	3.96	4	1.5
Y1	15.55	3.96	4	1.5
Y2	17	3	4	1.5
Y3	21	5	4	3
Y4	20	4	6	3

Outer diameter

$$D_2 = \frac{2U_2}{\omega}$$

$$= \frac{2 \times 21.03 \times 60}{2 \times \pi \times 2800}$$

= 143.43mm

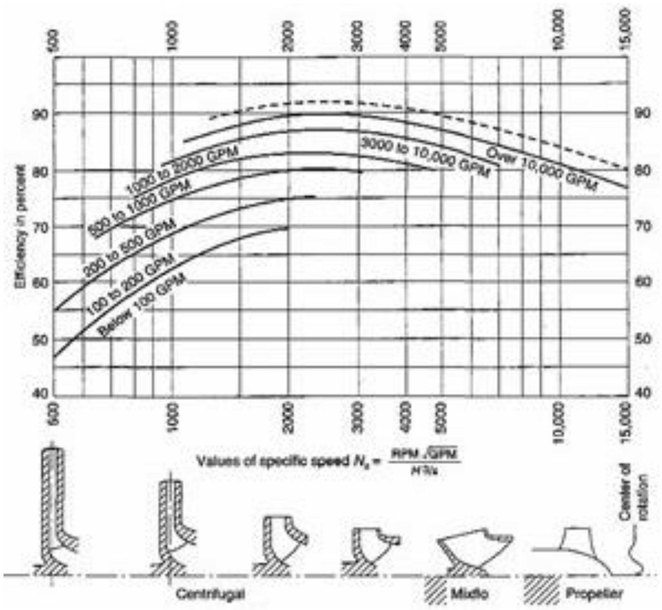

Fig - 6: Curve depicting the relationship between efficiency and specific speed

Step 3: **Calculation of impeller width**

Impeller exit width

$$B_2 = \frac{Q}{\pi D_2 U_2 \varnothing}$$

$$= \frac{0.00396}{\pi \times 0.14343 \times 21.03 \times 0.08}$$

= 5.224×10^{-3} m
= 5.224mm

Step 4: **Calculation of inlet diameter**

Initially, the optimum inlet diameter corresponding to an inlet blade angle *β1* of 24° should be calculated from

Optimum inlet diameter

$$D_2 = 1.533\sqrt[3]{\frac{Q}{\omega}}$$

$$= 1.533\sqrt[3]{\frac{0.00396}{293.22}}$$

= 0.03651m
=36.51mm

Step 5: **Calculation of outlet vane angle**

Assuming the following values for the coefficients, head coefficient Ψ = 0.6, discharge coefficient $\varnothing$ = 0.08 and slip coefficient σ = 0.8

Outlet vane angle

$$\beta_2 = \tan^{-1}\left(\frac{\sigma - \Psi}{\varnothing}\right)$$

$= \tan^{-1}\left(\frac{0.82-0.6}{0.08}\right)$

= 70.02 from meridian = 20 from tangential

Step 6: **Calculation of radius of curvature of vane**

Calculation of radius of curvature of vane

$$R_c = \frac{1}{2}\left(\frac{R_2^2-R_1^2}{R_2\cos\beta_2-R_1\cos\beta_1}\right)$$

$$= \frac{1}{2}\left(\frac{71.75^2-18.255^2}{71.75\cos 20-18.255\cos 24}\right)$$

= 47.44mm

Step 7: **Calculation for determining number of vanes**

Calculation for determining number of vanes

$$Z = 6.5\left(\frac{D_2+D_1}{D_2-D_1}\right)\sin\left(\frac{\beta_2+\beta_1}{2}\right)$$

$$= 6.5\left(\frac{143.43+36.51}{143.43+36.51}\right)\sin\left(\frac{24+20}{2}\right)$$

≈ 4

This step marks the end of designing the impeller. The derived dimensions of the newly developed impeller are depicted in Figure below

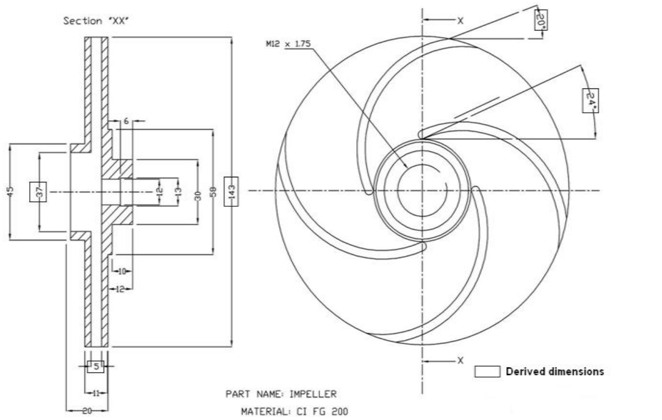

Fig - 7: New Impeller (Y1) With Derived Dimensions

3.4. DEVELOPMENT OF NEW CASING DESIGNS (PHASE II)

Keeping the existing casing design as reference, the dimensions of the new casing designs are derived using the following empirical relations. The development of new products using creative thinking is a major hallmark of AM. As a sample, the procedure used to develop a casing is shown as follows.

Step 1: **Calculation for determining the absolute tangential exit velocity**

Peripheral speed of impeller at inlet

$$U_1 = \frac{\pi D_1 N}{60}$$

$$= \frac{\pi \times 0.03654 \times 2800}{60}$$

$= 5.353$ m sec^{-1}

Peripheral speed of impeller at outlet

$U_1 = 21.03$m sec^{-1}

Outlet vane angle

$$\beta_1 = \tan^{-1}\left(\frac{V_{f1}}{U_1}\right)$$

Inlet flow velocity

$V_{f1} = U_1 \tan\beta_1$

$= 5.353 \times \tan 24$

$= 2.38$ m sec^{-1}

Since constant velocity flow is assumed,

$V_{f1} = V_{f2} = 2.38$m sec^{-1}

$$\tan\beta_2 = \frac{V_{f2}}{U_2 - CT_2}$$

$$\tan 20 = \frac{2.38}{21.03 - CT_2}$$

$CT_2 = 14.5$ m sec^{-1}

Step 2: **Calculation for determining the base circle diameter**

Base circle diameter of casing

$D_3 = 1.1 D_2$

$= 1.1 \times 0.14343$

$= 0.1578$m

$= 157.8$mm

Assuming the velocity reduction due to increased cross-sectional area as 10%,

The velocity at throat outlet

$CQ_3 = 0.9 CT_2$

$= 0.9 \times 14.5$

$= 13.05$ m sec^{-1}

Step 3: **Calculation for determining the throat area and throat diameter**

Throat area $= \frac{\pi D^2}{4}$

$= \frac{Q}{CQ_3} = \frac{0.00396}{1305}$

$= 3.0345 \times 10^{-4} m^2$

Throat diameter d $= \sqrt{\frac{4A}{\pi}}$

$$= \sqrt{\frac{4(3.0345\times10^{-4})}{\pi}}$$

= 19.66mm =0.01966m

***Step 4:* Calculation for determining the optimum throat area and throat diameter**

Calculation for determining the optimum throat area and throat diameter However, the centre of the throat area will move to a radius of $(D2 + d)/2$, and the velocity approaching the throat will slowdown in inverse proportion to the distance from the impeller centre. Therefore, the throat velocity will diminish to

$$CQ_3 = CT_2\left(\frac{D_2}{D_1 + d}\right)$$

$$= 14.5\left(\frac{0.14343}{0.1578 + 0.02327}\right)$$

$$= 11.48 \text{ m sec}^{-1}$$

Therefore, the corrected area will become

$$A = \frac{Q}{CQ_3}$$

$$= \frac{0.00396}{11.48}.$$

$$= 3.45 \times 10^{-4} m^2$$

Then corrected throat diameter

$$d = \sqrt{\frac{4A}{\pi}}$$

$$= \sqrt{\frac{4 \times (3.45 \times 10^{-4})}{\pi}}$$

$$= 0.021\text{m}$$

$$= 21\text{mm}$$

This step marks the end of designing the casing. The CAD model of the newly developed casing design is shown in Fig 8.

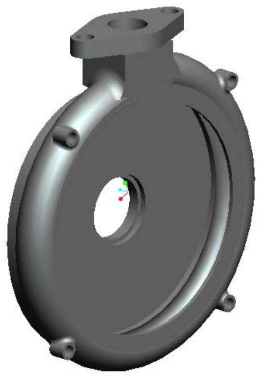

Fig -8: 3D CAD Model of the Proposed Casing Design

3.5. ANALYSIS OF IMPELLER DESIGNS AND MANUFACTURING FEASIBILITY STUDY (PHASES III AND IV)

Engineering analysis is an important phase in product design cycle. The analysis ensures the capability of designs for further processing. The proposed new impeller designs have been subjected to flow analysis using GAMBIT and FLUENT software.

GAMBIT is mesh generation software that provides interface for creating and meshing the geometries. GAMBIT acts as a preprocessor for processing the geometries before performing flow analysis.

FLUENT is a general purpose CFD software which is suited for performing fluid flow analysis. It is a solver based on the finite volume method. The post-processing tools of FLUENT can be used to generate animations as well as the generation of reports that convey the results of CFD analysis. The generated CAD models of the new impeller designs are subjected to flow analysis. The meshing of the impeller designs is carried out using GAMBIT preprocessor. The type of mesh element employed is hexahedral and fine meshing has been defined. The first impeller design after meshing is shown in Fig 9. The meshed impeller model has been subjected to flow analysis by importing in the form of mesh file. The input parameters have been set as input flow velocity (2.38 m sec^{-1}) and outlet pressure (atmospheric pressure). In our case, the output parameter to be considered is mass flow rate. The screen containing the specification of boundary conditions is shown in Fig 9.

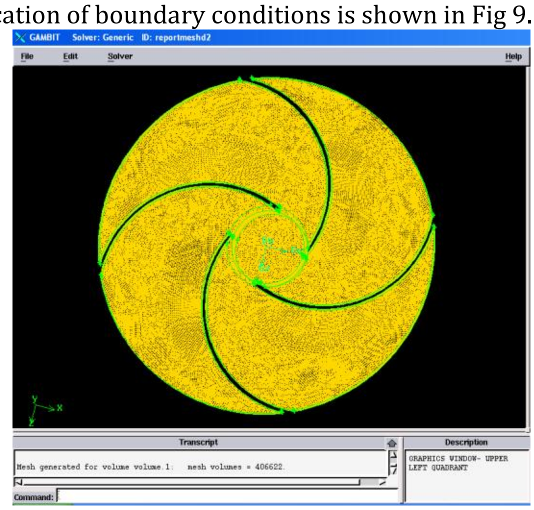

Fig - 9: Screen Depicting the Meshed Impeller (D1)

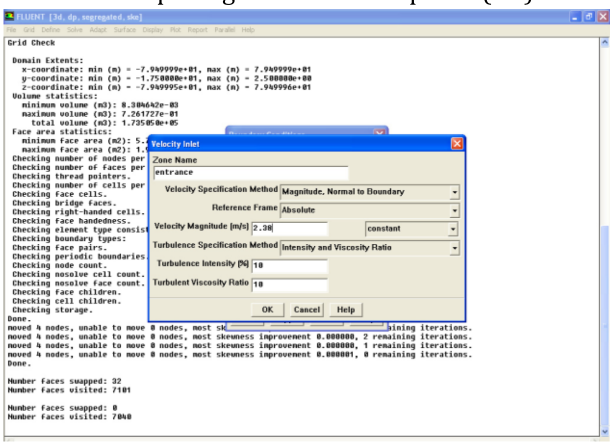

Fig - 10: Screen Enabling the Specification of Input Parameters

As observed from Fig 10, the mass flow rate is found to be 3.864675 kg sec^{-1}. The analyzed designs need to be subjected to manufacturing feasibility analysis to ensure the manufacturability of designs. The manufacturing feasibility study of impeller designs has been carried out using 'Cast Cavity' module of Pro/Engineer Wildfire 3.0. After importing the impeller model, the desired shrinkage allowance needs to be specified. Since the impeller material is ferrite graphite iron, the shrinkage allowance is 1.1.

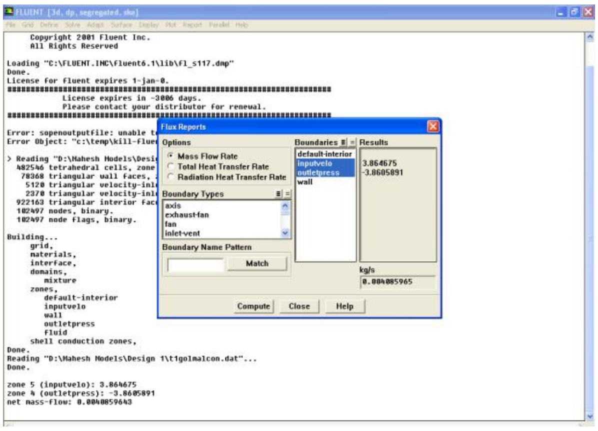

Fig - 11: Screen Enabling the Generation of Output Parameter

4. CONCLUSIONS

Today, the manufacturing organizations are facing stiff competition to meet the varied dynamic requirements of the customers (Quintana, 1998). Though certain manufacturing sectors like mobile phone manufacturers are bringing out different models within a short period of time, certain traditional manufacturing sectors like pumps, compressors and machine tool manufacturers are not able to bring out different varieties within a short period of time. The fundamental reason behind this kind of situation is that, there is no proper linkage between AM, design engineering and advanced technologies. The literature review on AM also indicated the missing link between design engineering and AM (Kusiak and He, 1998). This typical situation prevailed in the organization where the case study has been carried out. The experiences of conducting this case study proved the phenomenon that CAD/CAM act as enabler for AM which has been stated theoretically by many AM researchers (Gunasekaran, 1998; Onuh and Hon 2001). In this context, this study fulfils the research void. The opinions of the experts working exclusively in the design and manufacturing of pumps also suggested the practical feasibility of the generated designs. This kind of technology integration in the AM field would enable the traditional manufacturing organizations to survive in the competitive environment of unanticipated changes to become winners in the global market scenario (Lin and Uhler, 2002; Pires et al., 2004).

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