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Optimum Structural Design of Vertical Milling Machine

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ABSTRACT

This study work proposes a methodology for optimization of structural design for mini milling machine with considering material selection criteria. Most of the cases in vertical milling the structure is manufactured in casting, and in the design consideration structural layout gives less importance. This paper shows the details and results of operations concerning the selection of material for a modification in design of vertical milling machine, with regards to the generation and pre-selection of the numerous variants with reference to present structure. The selection of material by analytical hierarchy process and design of a suitable layout can best be carried out by software base model generation. Studies carried out on hybrid machine tool structures proved it to be an alternative for the challenge posed by the conventional solo-materials structure. This study search for a new alternative like a hybrid structure with combination of casting as well as fabricated structure on current structural layout combination which covering requirements of design constraints. Model generation on the structural combination on the basis of material selection for base in cast iron grade 35 and frame in steel grade AISI 1080. In the material selection by AHP method the different materials will compare on property basis by considering application. It will provide a resultant damping ratio and stiff structure with better design flexibility. Also, it will beneficial for minimize weight, cost with better design of structure as compared to present cast iron structure.

Keywords— **AHP method, Hybrid structure, Material Selection, Vertical milling machine**

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I. INTRODUCTION

The impact of structural parameters on performance of mechanical element is also a equally important with machining parameters. This paper shoes a conceptual design with considering a structural and material impact on machine design. For this study we selected a compact structure of vertical milling machine which is low-cost milling machines for home and workshop use. While these machines are small in size, with proper adjustment and techniques they can make a wide range of very useful and reasonably precise components that would be difficult or impossible to make by any other means. The mill is an excellent compliment to a lathe, for making things that cannot be made on a lathe. Because lathes are capable mainly of making shapes based on cylinders, a mill is needed for making other parts that are based on cubical shapes rather than cylindrical shapes. With a lathe and a mill together, you can make just about anything you might need in the way of small precision parts.

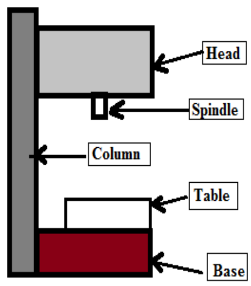

Fig 1: Layout of vertical milling structure

Fig.1 shows a layout of vertical milling machine structure which is mostly manufactured in casting, here in this study we search for a new alternative like a hybrid structure with combination of casting as well as fabricated structure which covering requirements of design constraints with analyzing the stiffness and in minimum cost and material consumption. As discussed earlier milling machine mostly the standard structure is in casting form provided by manufacturer. But casted structure is carrying more material with heavier size and high cost. There is need to search another option which fulfil the design requirements in cheaper cost and with minimum material consumption. For that selection of proper material is a main task in design stage.

Traditionally, the base and other major components of a machine tool have been made of gray or nodular cast iron, which has the advantages of low cost and good damping, but the disadvantage of heavy weight. In modern equipment design, lightweight structures are desirable because of ease of transportation, higher natural frequencies, and lower inertial forces of moving members [6]. Lightweight designs are a basic goal in rapid machine design and require fabrication processes such as mechanical fastening (bolts and nuts) of individual components and welding.

Hybrid menaces a combination. In a hybrid structure there is combination of two or more structural design options and forms a new one. But for better design of hybrid structure there is need of perfect selection of material with requirement of component with best combination achieve a better result than existed structure. However, fabricated structures have also a few disadvantages associated. These include:

- Comparably high variable costs prohibit large production volumes.
- Structures generally need stress-relief either through thermal or vibrational relaxation.
- All welds should be reasonably accessible, imposing sometimes hard to meet design constraints.
- Fabricated structures have much less damping compared to cast-iron based designs, requiring other forms of damping such as constrained layer damping.

With considering advantages and disadvantages of fabricated and casted structure, there is need of manufacturing a structure in hybrid way. Despite the shortcomings listed above, designing and building a machine as a hybrid structure has the big advantage of a much lighter design, a substantially shorter lead-time compared to a cast design with a better design option. This is especially true for the case where the base is built from round tubes as opposed to flat plates, because round structures offer better strength-to-weight ratios and are more readily available

New design of structure is supposed to be suitable for the compact vertical milling machine of wide range with less weight, with lesser material consumption and with easily affordable price and with follows all acceptable criterions like load, static and dynamic stiffness, vibrational stability etc. This will be done by working on selection of best suitable material selection, manufacturing processes, joining techniques along with designing in CAD, and software analysis of design by FEA tool.

Studies carried out on hybrid machine tool structures proved it to be an alternative for the challenge posed by the conventional solo-materials structure. Research is on to study the characteristics exhibited by hybrid machine structures by varying structural design with combination of different material components in it [4]. Results indicate that with the combination of cast iron base and fabricated steel head structure structures will provide a resultant damping ratio and stiff structure with better design flexibility. Also, it will beneficial for minimize weight, cost with better design of structure as compared to present cast iron structure

Here in this study we search for a new alternative like a fabricated structure with all covering requirements of design constraints with analyzing the parameters. Determination Of Overall portion and dimensions of supporting framework & selection of individual members. It should according to the requirements of customer or client. It should be according to safety requirements, Serviceability i.e. how well structure performs in terms of appearance & deflection and economy structure should be with efficient use of material.

II. MATERIAL SELECTION IN DESIGN

Material section is a main step in designing process to select the appropriate materials for each element of the machine so that they can sustain all the forces and at the same time they have least possible cost

A. Relation of Materials Selection to Design

An incorrectly chosen material can lead not only to failure of he part but also to excessive life-cycle cost. Selecting the best material for a part involves more than choosing both a material that has the properties to provide the necessary performance in service and the processing methods used to create the finished part as in Fig 2. A poorly chosen material can add to manufacturing cost. Properties of the material can be enhanced or diminished by processing, and that may affect the service performance of the part.

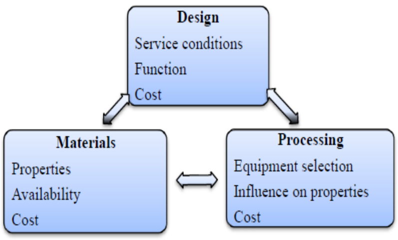

Fig.2 Relationship of design, material & processing to produce a product

In the large number of combinations of materials and processes from which to choose, the materials selection task can only be done effectively by applying simplification and systemization. As design proceeds from concept design, to configuration and parametric design embodiment design, and to detail design, the material and process selection becomes more detailed. Fig 3. Compares the design methods and tools used at each design stage with materials and processes selection. At the concept level of design, essentially all materials and processes are considered in broad detail.(E. Kushnir et al. 2001)

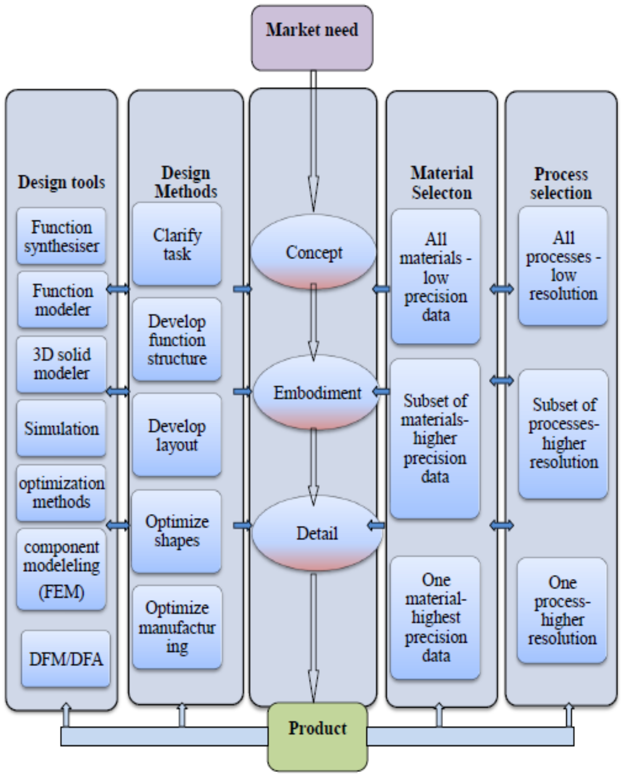

Fig.3. Process flow diagram of product design. (Dieter G. 2008)

B. Materials Substitution in an Existing Design

In this situation the following steps pertain:

1) Characterize the currently used material in terms of performance, manufacturing requirements, and cost.
2) Determine which properties must be improved for enhanced product function. Of. ten failure analysis reports play a critical role in this step
3) Search for alternative materials and/or manufacturing routes. Use the idea of screening properties to good advantage.
4) Compile a short list of materials and processing routes, and use these to estimate the costs of manufactured parts
5) Evaluate the results of step 4 and make a recommendation for a replacement material. Define the critical properties with specifications or testing, as in step 5 of the previous section.

C. Methods of Material Selection

There is no single method of materials selection that has evolved to a position of prominence. This is partly due to the complexity of the comparisons and trade-offs that must be made.

Some of the more common and more analytical methods of materials selection are:

1. Selection with computer-aided databases
2. Performance indices
3. Decision matrices
   - Pugh selection method
   - Weighted property index
   - Analytic Hierarchy Process (AHP) Method.

D. Analytic Hierarchy Process (AHP) Method

One of the most popular analytical techniques for complex decision making problems is the Analytic Hierarchy Process (AHP). Saaty developed AHP which decomposes a decision making problem into a system of hierarchies of objectives, attributes (or criteria) and alternatives. The main procedure of AHP using geometric mean method is as follows:

Step 1: Determine the objective and the evaluation criteria.

Step 2: Find out the relative important MATRIX of different criteria with respect to the goal or objective. Construct a pair-wise comparison matrix using a scale of relative importance.

Numerical assessment	Linguistic meaning
1	Equal importance
3	Moderately more importance
5	Strongly more importance
7	Very strongly importance
9	Extremely more importance
2,4,6,8	Intermediate value of importance

Step 3: The next step is to compare the alternatives pair-wise with respect to how much better (*i.e.*, more dominant) in satisfying each of the criteria.

Step 4: The next step is to obtain the overall or composite performance scores for the alternatives by multiplying the relative normalized weight (w_j) of each criteria with its corresponding normalized weight value for each alternative and making summation over all the criteria for each alternative [1].

III. Material selection for Individual component

Spindle head and structure bed material get selected separately.

A. Column:

Steel Grades

According to the World Steel Association, there are over 3,500 different grades of steel, encompassing unique physical, chemical and environmental properties.

In essence, steel is composed of iron and carbon, although it is the amount of carbon, as well as the level of impurities and additional alloying elements that determines the properties of each steel grade.

The carbon content in steel can range from 0.1-1.5%, but the most widely used grades of steel contain only 0.1-0.25% carbon. Elements such as manganese, phosphorus and sulphur are found in all grades of steel, but, whereas manganese provides beneficial effects, phosphorus and sulphur are deleterious to steel's strength and durability.

Different types of steel are produced according to the properties required for their application, and various grading systems are used to distinguish steels based on these properties According to the American Iron and Steel Institute (AISI), steels can be broadly categorized into four groups based on their chemical compositions:

The study represents simultaneous cost, topology & standard cross section optimization of single storey building structures. The considered structures are consisted from main portal frames, which are mutually connected with purlins. The optimization is performed by the Genetic Algorithm (GA). The proposed Algorithm minimizes the structures material &labor cost, determines the optimal topology with the optimal number of portal frames & purlins as well as the optimal standard cross sections of the steel.

This paper concluded that Genetic Algorithm method is most suitable for solving the encountered problem in civil engineering. The mathematical problem such as derivatives, Integration are not included in this method which makes the method easy to use.The main aim of paper is to obtain the simultaneous cost, topology & standard cross section optimization of single storey industrial building structures.[2]

1.Carbon Steels 2. Alloy Steels

3.Stainless Steels 4.Tool Steels

As per the various literature study and references on structural design of machine most common material to be taken for consideration of in machine design are study Steel Grade 1015, 1040, 1080 1070.Hence these material were taken for comparison base analysis.

As per analysis Grade 1070 & Grade 1080 have similar compared properties, Hence for comparison here considering Steel grade 1015, 1040 & 1080

Table 1: Properties to be consider for material selection of material

Abbreviation	Properties	Unit
D	Density	x10^3 kg/m3
TS	Tensile Strength	Mpa
YS	Yield Strength	Mpa
EL	Elongation	%
RA	Reduction in Area	%
H	Hardness	HB
IS	Impact Strength	J
TE	Thermal Expansion	10^{-6}/ºC

Table 2: Material consider for study

H1	Steel carbon AISI 1015
H2	Steel carbon AISI 1040
H3	Steel carbon AISI 1080

Beneficial Criteria (H) : Density, Tensile Strength, Yield Strength, Hardness, Impact Strength

Non-Beneficial criteria (L) : Elongation, Reduction in Area, Thermal Expansion

Tab 4: Pair wise importance matrix

Criteria Consideration	**H**	**H**	**H**	**L**	**L**	**H**	**H**	**L**
Properties	**D**	**TS**	**YS**	**E**	**RA**	**H**	**IS**	**TE**
D	1	4	3	5	3	4	3	5
TS	0.25	1	3	5	5	4	3	3
YS	0.333	0.333	1	5	5	5	3	5
E	0.2	0.2	0.2	1	3	5	3	5
RA	0.333	0.2	0.2	0.333	1	5	3	3
H	0.25	0.25	0.2	0.2	0.2	1	3	5
IS	0.333	0.333	0.333	0.333	0.333	0.333	1	5
TE	0.2	0.333	0.2	0.2	0.333	0.2	0.2	1

Properties	Geometric Mean	Weight
D	3.192845983	0.299817
TS	2.257683046	0.212002
YS	1.948660659	0.182984
E	1.076239836	0.101062
RA	0.817560916	0.076771
H	0.542478659	0.05094
IS	0.53604892	0.050336
TE	0.277814434	0.026088
Total	**10.64933245**	**1**

Table 5: Typical properties for Frame material for design of structure

Criteria Consideration	**H**	**H**	**H**	**L**	**L**	**H**	**H**	**L**
Material/ Properties	**D**	**TS**	**YS**	**E**	**RA**	**H**	**IS**	**TE**
H1	7.7	386.1	284.4	37	69.7	111	115	11.9
H2	7.8	518.	353.	30.	57.	14	44.	13.

	5	8	4	2	2	9	3	6
H3	7.9	615.4	375.8	24.7	45	174	6.1	14.7

Criteria Consideration	**H**	**H**	**H**	**L**	**L**	**H**	**H**	**L**
Mat. / Properties	**D**	**TS**	**YS**	**E**	**RA**	**H**	**IS**	**TE**
H1	0.9747	0.6274	0.7568	0.6676	0.6456	0.6379	1	1
H2	0.9937	0.843	0.9404	0.8179	0.7867	0.8563	0.3852	0.875
H3	1	1	1	1	1	1	0.053	0.8095

Calculation for Ranking = (Normalized matrix) x (weight)

Normalized matrix X Weight	**Ranking**
0.7875	3
0.87957	2
0.9523	1

Hence as per analysis Steel grade 1080 is better material foe structure making in mini milling machine which fulfil all the requirements of design.

B. Bed:

The three most popular choices currently used for the main structural components of machine tools are steel weldments, metal (cast iron) castings and polymer composites.

All three approaches have been employed in the design of machine tools to meet the criteria for required rigidity, impact resistance and vibration damping. The final choice is also affected by additional factors including cost footprint (space) requirements and lead times.

By studying various literature reviews & different excellent properties of material & availability here will compare above three materials and will select best one by using AHP method.

Calculation of criteria weightage by using AHP

Pair wise comparison matrix which is used to find criteria weightage is as follows:

Tab 6: Properties to be consider for material selection of material

Notation	**Properties**	**Unit**
ME	Modulus of Elasticity	GPa
PS	Poisson Ratio	---
D	Density	Kg/m^3
TS	Tensile Strength	MPa
CS	Compressive Strength	MPa
DAM	Damping Ratio	---

Tab 7: Material consider for study

M1	Steel carbon (low alloy)
M2	Cast Iron (Grade 35 Gray)
M3	Polymer composite

Tab 8: Pair wise importance matrix

Criteria consideration	**L**	**H**	**H**	**L**	**H**	**L**
Properties	**ME**	**D**	**CS**	**TS**	**DAM**	**PS**
ME	1	3	3	2	5	5
D	0.333	1	3	2	5	5
CS	0.333	0.333	1	2	5	5
TS	0.5	0.5	0.5	1	5	5
DAM	0.2	0.2	0.2	0.2	1	1
PS	0.2	0.2	0.2	0.2	1	1

Criteria consideration Properties	**Geom. Mean**	**Weight**
ME	2.768229	0.34993
D	1.919063	0.242588
CS	1.330382	0.168173
TS	1.209136	0.152846
DAM	0.341995	0.043231
PS	0.341995	0.043231
TOTAL	**7.91080**	**1**

Tab.9: Typical properties for material for design of structure

	L	**H**	**H**	**L**	**H**	**L**
	ME	**D**	**CS**	**TS**	**DAM**	**PS**
M1	30	0.28	0	61000	0.00008	0.3
M2	15	0.26	116000	30000	0.00085	0.27
M3	5.4	0.093	15600	2290	0.008	0.24

Tab 10: Normalized matrix

	ME	**D**	**CS**	**TS**	**DAM**	**PS**
M1	0.18	1	0	0.0375	0.01	0.8
M2	0.36	0.9285	1	0.0763	0.1062	0.8889
M3	1	0.3321	0.1344	1	1	1

Tab 11: Ranking of material as per the Weightage by calculation

Normalized matrix x weight	Ranking
0.346324	3
0.574072	2
0.692405	1

Tab 12: Ranking of material as per Cost, Availability and Manufacturability

	M1	M2	M3
Cost	2	1	3
Availability	2	1	3
Manufacturability	2	1	3

Model generation on the basis of selected material by using CAD software which is suggested model as shown in fig.4.

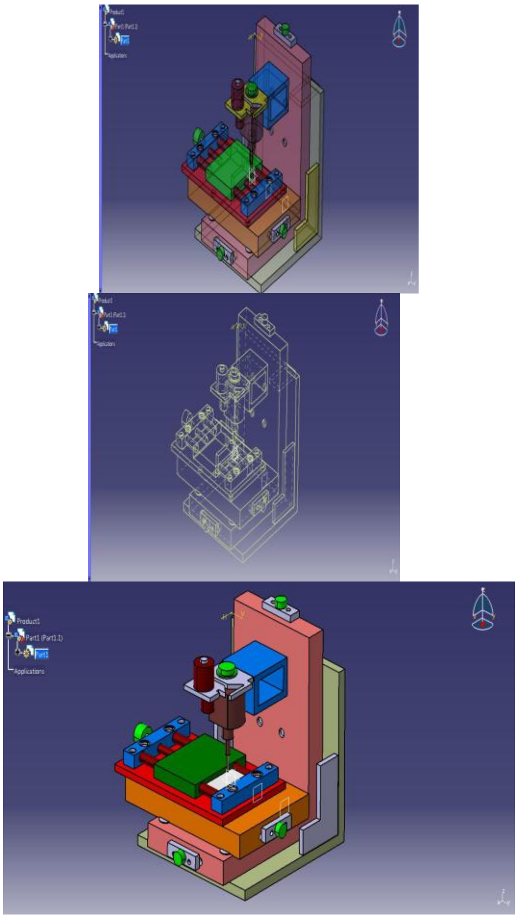

Fig.4: Suggested CAD based model.

V. CONCLUDING REMARKS

Hence as per analysis in the structural design the material will get selected by AHP method for bed is cast iron grade 35 gray and Steel grade AISI 1080 is better material for structure of spindle column making in mini milling machine which fulfil all the requirements of design and from this analysis will get a hybrid design option for structure with a greater flexibility.

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REFERENCES

[1] Syath Abhuthakeer, P.V. Mohanram, G. Mohan Kumar, Structural redesigning of a CNC lathe bed to improve its static and dynamic characteristics, 2011, Faculty of engineering - hunedoara, Romania, 389-394

[2] Ishan B Shah, Kishore. R. Gawande, Optimization of Cutting Tool Life on CNC Milling Machine Through Design Of Experimnets-A Suitable Approach – An overview, 2012, IJEAT-189-194

[3] A.Selvakumar, P.V. Mohanram, Analysis of alternative composite material for high speed precision machine tool structures. department of mechanical engineering, psg college of technology, coimbatore – tamil nadu, india 641 004.

[4] Emmanuil F. Kushnir; Mahendra R. Patel; Terrence M. Sheehan Hardinge Inc., Elmira, Material Considerations in Optimization of Machine Tool Structure, Proceedings of 2001 ASME International Mechanical Engineering Congress and Exposition November 2001, New York, NY 11–16,

[5] TALAT (Lecture 1502)'Criteria in Material Selection, 36 pages, 38 figures Advanced Level Iprepared by: Rolf Sandström, Stockholm

[6] Kalpak Jain, ,Manufacturing engg. and technology (6^{th} edition)

[7] Modern Steels and their properties (Carbon and Alloy Steel Bars and Rods), Akron Steel Treating Company (AST)

[8] http://www.steelgr.com/Steel-Grades/Carbon-Steel/aisi-1080.html retrieved on 2014, April, 24.

