Structural Optimization of Reconfigurable Machine Tool

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Abstract-This work proposes structural optimization that considers design reconfigurability in configurable machine tool. The configurable machine tool is reconfigured to perform well under different considered loading conditions in different configurations. The configurable machine is modeled in ANSYS and a dynamic analysis is conducted to check frequency, deformation values for different modes. Based on the results of the analysis, the machine tool components which are highly stressed is identified and a parameter based optimization is done on machine tool component for achieving reconfigurability. The design criteria used in this paper as machining accuracy, subject to structural constraints. The introduction of this reconfigurability into structural design leads to significant benefits such as reduced manufacturing cost.

Keywords—*Configurability, Macros, Modules, Configuration, Frequency, Deformation, Accuracy.*

I. INTRODUCTION

A reconfigurable machine is composed of modules that are interchangeable and can be configured to create various structural designs. Structural reconfigurability is the ability of the configuration to be modified in order to respond to different machining requirement such as milling operation, lathe operation, drilling operation a module is a set of elements arranged to perform a single component function Reconfiguration can be done by rearrange the modular into newer combination.

An important aspect to be considered in structural optimization is loading condition variation. In this work, we propose a new design optimization methodology that deals with structural optimization considering many different loading conditions arises with configuration variations. These loading conditions are not at all simultaneous to the structure. The goal is to make reconfigurable system that it can deal with these various loading conditions well. While robust design is a passive response to different loading conditions, design for reconfigurability is an active response.

Pantelides and Ganzerli performed truss structure design optimization for uncertain loading conditions. Loading uncertainties of magnitude and direction were considered and optimization objectives of structural volume and displacement were minimized. (1)

Bendsøe and Kikuchi first proposed the homogenization method for structural topology optimization, where a number of microstructures represent a structure. An optimality criterion method is used in the homogenization method, and it has been applied to a variety of problems. (2)

Yang et al. proposed artificial material and used mathematical programming for topology optimization.5 This method is easy to formulate and use. All the topology optimization method assumed a fixed number of design variables or a fixed design domain. (3)

Kim and Kwak proposed a concept of variable number of design variables, which results in a variable design domain. The generalized optimization, which is called as a design space optimization, was applied to structural topology optimization and plate optimization. One major component of flexible design, modularity, has been studied as a component of structural design. (4)

Nishigaki, Nishiwaki, Amago, and Kikuchi.7 In their research, Cetin et. al. performed a two-step optimization process in which an optimal structural topology design was decomposed into optimal modular components. Structural strength, assemblability, and modularity were considered in the decomposition optimization problem. It can be seen in the literature survey that while research has been done on structural topology optimization as well as topics such as modularity, no research has been done on structural topology optimization considering design reconfigurability, that too in machine tools, it is newer. (5)

The goal of this research is to investigate the manufacturing cost benefits resulting from the incorporation of reconfigurability into structural design by studying the effects of design reconfigurability in configurable machine tools.

II. PROBLEM STATEMENT

The idea is to develop a set of module that can be reconfigured to form various machine tool configurations for different machining requirements. We used an important standard to represent the performance of the machine design is accuracy.

The procedure used to design the individual modulus or components of a reconfigurable tool is shown in Fig. 1. This illustrative example is of a truss structure subject to various loading conditions. The aim is to obtain the components of reconfigurable tools to withstand all loading conditions.

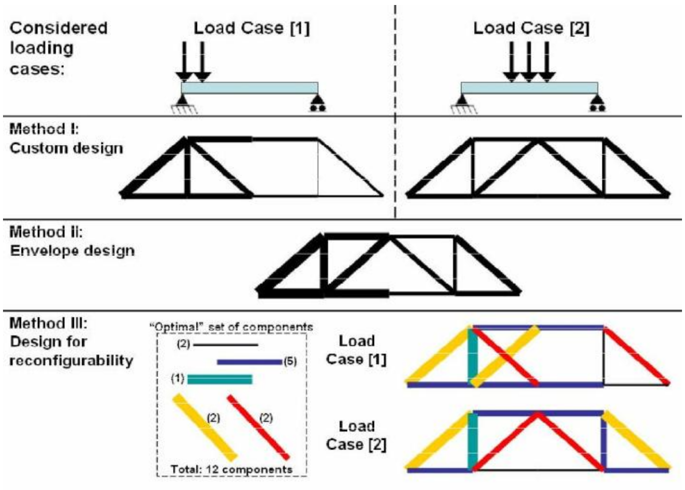

Figure 1: Optimization method for different Loading condition

III. METHODOLOGY

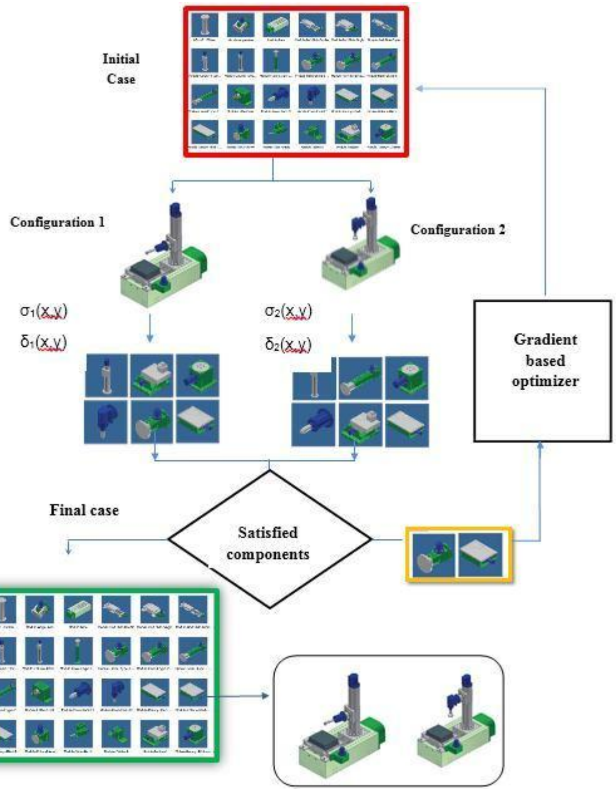

Figure.2: Design methodology

The fig 4.1 shows the basic methodology of structural optimization of reconfigurable machine tool in that a set of components for the different configuration are taken, these components are analyzed and optimized to satisfy different configuration. The satisfied components are taken separately and not-satisfied components are considered for optimization based on gradient based optimizer to satisfy configuration requirement of reconfigurable machine tool.

IV. MODEL DEVELOPMENTS AND LOAD VARIATIONS

Milling machine is taken as the reconfigurable system for the proposed model. The module and components are designed by observing the existing machines with same function, structure and configuration. The geometrical features including functional features are studied and the variations are recorded. A trade-off is made between the module and new modules are designed with features to overcome the variations. Module of the different configurations are modeled in ANSYS using macros for separate modules/parts.

Macros are a sequence of ANSYS commands stored in a file. After designing the components/modules, the configurable machine is represented and modeled as assemblage of modules as per the connectivity in the configuration design. An APDL code is written for modelling which takes necessary inputs from the user and automatically runs to form the desired model.

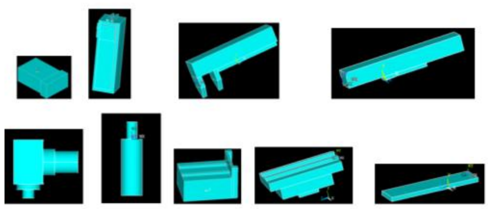

Figure 3: Modules of RMT

Table.1: Details of Reference machine (VMM)

Components	shape	Volumetric Size (mm)	Functions
Base	Rectangle	1100*520	Provide mounting and supports for column
Column	Box type	325*315	Provide sliding surface for knee Provide mounting and supports for arbor arm
Arbor arm	Box type	1000*165	Supports the arbor
Table	Rectangle	1300*230	Work piece clamping
Saddle	Rectangle	500*315	Provide linear motion to table
Knee	Rectangle	800*315	Provide linear motion to saddle

From the above details of components of milling machine two possible configurations of assemblage can be formed, accordingly vertical and horizontal milling machine configurations are obtained.

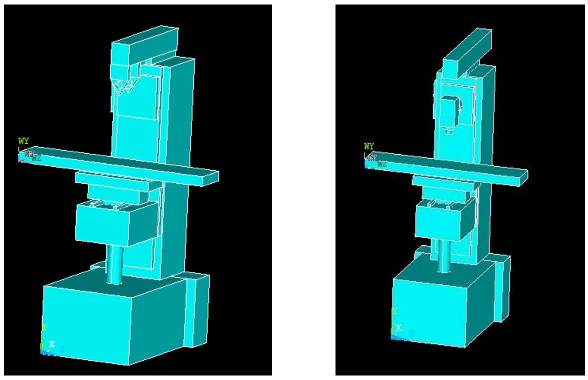

Figure. 4: Configurations (Horizontal and Vertical)

In this, the existing design is studied thoroughly. Then the desired design is implemented in the current design i.e., re-engineering process. The design is analyzed for the strength criteria using analysis software ANSYS. The analyzed model is then compared with reference machine and it is validated. The machine tools are usually design for the loading conditions coming with machining operation. In this study the milling machine configurations are considered and are characterized with a range of operations such as gear cutting, keyway, grinding etc., For the purpose of design, we took end milling with ball nose cutter and the work piece material is AISI 1045steel.Average forces and acceptable deformations for different milling operation

Roughing Conventional tools: 1,500 N

100–125 mm. diam. tools: 3,000 N

Average deformation: 100 µm

Semi-finishing Conventional tools: 1,000 N, Average: 50 µm

Finishing Conventional tools: 200 N, Average: 10 µm

Milling machine is mostly subjected to dynamic vibration that affects the accuracy of the machine. Also for different loading or processing of the machine has influence on the accuracy. So a dynamic analysis is performed on the machine to check the frequency and deformation values. Average forces and acceptable deformations for different milling operations are also checked.

The applied material properties are presented in Table 2

Table 2: Material Properties

Material	Cast iron
Density(kg/m^3)	7250
Poisson's Ratio	0.287
Modulus of elasticity	83-170 GPa
Ultimate tensile stress	478 Mpa

The component structures were modeled using finite element analysis with ANSYS software. Dynamic loading cases (cutting force on the frame) were considered. It was assumed that these loading cases give access to the properties that the designer wishes to tailor and, therefore, are valid as a basis for the design. A variant of module can be redefined and designed by modifying the geometry of the model. The modal analysis of two different configurations are shown below

Configuration-I:

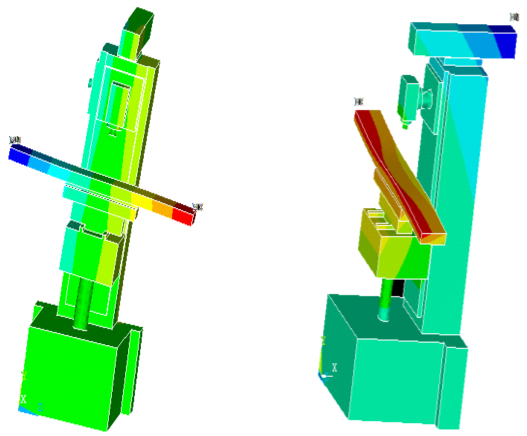

Figure.5: Failure modes

Configuration-II

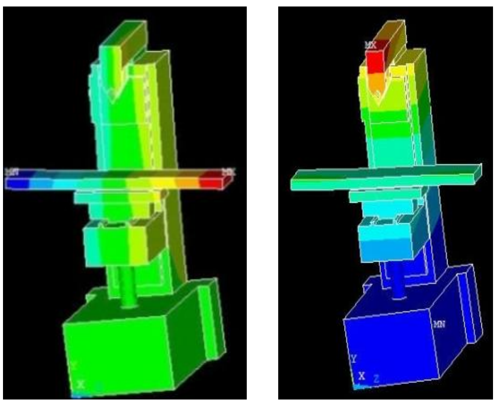

Figure .6: Failure Modes

V. RESULTS AND DISCUSSION

The following results were observed during the analysis,

Configuration I:

No. of modes to expand: 10

Table.3.frequency and deformation

Type of mode	Frequency(Hz)	Deformation(mm)
Translation x	0,935787	0.634E-05
Translation y	1.093	0.592E-04
Translation z	1.64	0.716E-04
Rotation x	1.905	0.229E-03
Rotation y	1.905	0.229E-03
Rotation z	2.238	0.279E-03
Twist	2.533	0.210E-03
Warp	2.636	0.210E-03
Bend	3.737	0.319E-03
Shear	3.952	0.272E-03

Configuration II:

No. of modes to expand: 3

Table.4: Frequency and Deformation

Type of mode	Frequency(Hz)	Deformation(mm)
Translation x	0.999327	0.701E-04
Translation y	0.999327	0.701E-04
Translation z	0.999327	0.701E-04

While analyzing the different configuration, the frequency and deformation values exceeded in some modes of failure. The work is done with the aim to finalize the values of different configuration modules within the limit of reference machine value for validation. So, the changes in the design of configurations were done often. Thus, we obtain different set of frequency and deformation values. But, the changes in the design were done till the values of all the configurations to be obtained under the range of reference values. Even a single change in the dimensions of any one configuration module is implemented in all the configurations and the optimized configurable configurations were obtained.

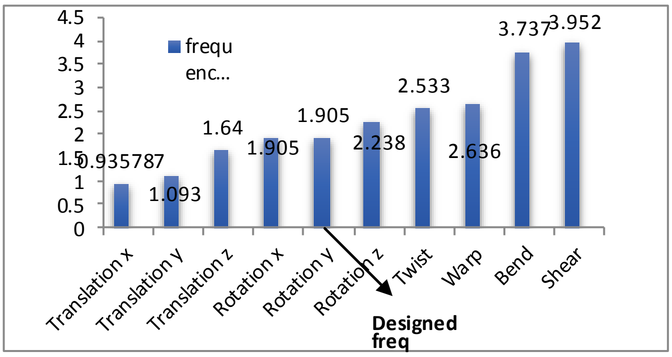

Figure 7: Frequency chart

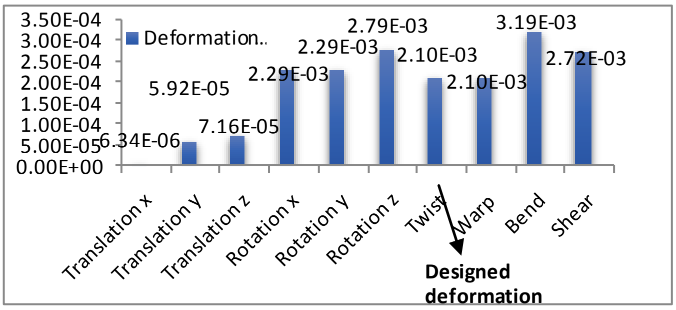

Figure 8: Deformation chart

The modules with deformation above the designed are taken for optimization to have the accuracy of the machine within the limit. So further structural optimization is carried to have the optimized configurations.

OPTIMIZATION: Design for Reconfigurability

Based on the Stress values from the Reconfigurable Machine Tool, the week component will be taken into the component level Design Optimization process, the component level Elemental Stress values are considered and the Objectives of the Stress component are setted in the Ansys Environment. The Examplilinary results of component level design optimization process are shown in fig.

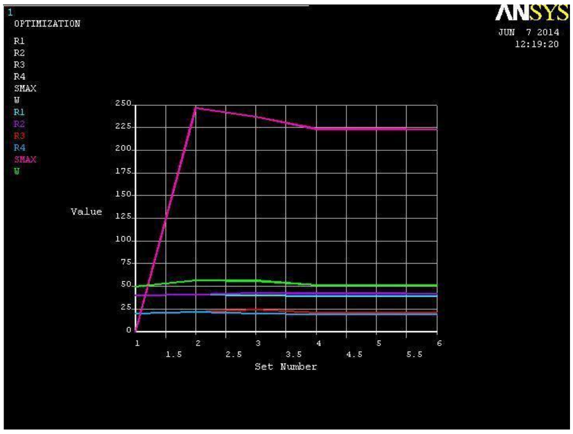

Figure 9: Examplilinary results of component level design optimization

CONCLUSION

The structural optimization of reconfigurable machine tool is carried out in ANSYS (APDL) and the structural, modal analysis of the Reconfigurable machine tool is also done using the ANSYS software. Based on the results of machine tool system the optimization of the machine tool components are identified and the parameter based optimization has been done for achieving reconfigurability in machine tool component.

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