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DESIGN AND ANALYSIS OF AN ASSEMBLY FIXTURE FOR THE COLUMN OF A CNC HORIZONTAL MACHINING CENTRE

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Abstract*- This work is carried out to design and analyse an assembly fixture for the column used in a CNC horizontal machining centre. Here the efforts are made to reduce overall set up time required for assembling the column in the machine. The objective was to study the existing mechanism and identifying critical parameters which influence the design of the assembly fixture. In this process, various new concepts were generated and comparison is made between them. A systematic new product design approach has been followed for generating new assembly fixture concepts. In this process, various tools & techniques such as Concept Classification Tree, Concept Combination Table and Concept Scoring Matrix are used. 4 different assembly fixture concepts were generated and best concept is selected with help of above stated tools. System design, detail design of the selected concept was carried out and 3D modelling was done using PTC Creo Elements Direct Modelling 17.0. Two dimensional manufacturing drawing of the fixture sub-components were generated in the last stage of design process*.

I. INTRODUCTION

A. Horizontal machining centre

A horizontal machining centre is an advanced CNC machine tool that can perform multiple machining operations like milling, drilling, tapping, and boring etc., at one single location/setup with a variety of tools. The capabilities of a machine tool are measured in terms of cost efficiency, throughput, reliability and quality. In a horizontal machining center the spindle axis is in horizontal direction. The essential functions of a machine tool are to provide a source of energy or relative motion and a means to secure the work piece, secure and orient the tool, and control the source of energy or motion and the orientation of the work piece and tool. To provide these functions, machine tools must employ four input flows, electric energy, cutting and lubrication oils, water, and compressed air, all of which have been regarded as cheap resources that can be excessively used to ensure high-quality finished products [1].

B. Column

Column, which will act as the back bone of all the machining centres is made up of thermally stable cast iron casings which are double stress relieved during the machining cycle to ensure dimensional stability over life cycle. It provides the optimal machining rigidity for retaining stability and accuracy. Here the machine is build with column moving in x axis. The column is installed on the bed where it will slide over the roller type LM guide ways and the ball screw provided will drive for the axis movement.

C. Assembly fixture

Fixtures are used to locate and immobilize parts or work pieces for assembly, machining, inspection and other kind of operations. Centering, locating, orientating, clamping and supporting can be considered the functional requirements of the fixtures. Fixtures are required in various industries according to their applications. Assembly fixtures are those used to locate the work piece for some assembly operations. Different types of assembly fixtures are developed in order to perform various tasks. For rear hub assembly of different automobile vehicles a slide assembly fixture was developed [2]. Fixtures are also developed in order to assemble various components like piston rings in piston ring grooves, for assembling parts of electronic devices [3], for assembling the inner splines of many clutch plates of a clutch housing [4], for assembly operations like soldering and spot gluing on inductors [5], for assembling basket used for transporting spent nuclear fuel rods [6], for assembling back combined pogo pin [7], for assembling automotive instrument panels [18], for assembling point contact devices such as transistors, for assembling electronic circuit modules and for assembly of fabricated rotor to the motors and generators.

II. DESIGN PROCESS OF FIXTURE MECHANISM

A generic new product development process is followed in design of the new assembly fixture.

A. Problem definition

The existing assembly set up uses two different arrangements for completing the assembly. So by designing a new assembly fixture for doing all the assembly operations and thereby reducing the set up time, operator requirement and safety concerns.

B. Five step concept generation method

This method breaks a complex problem into simpler sub-problems. Solution concepts are then identified for the sub-problems by external and internal search procedures. Classification tree and concept combination table are then used to systematically explore the space of solution concepts and to integrate the sub-problem solutions into a total solution. Finally a step is taken to reflect on the validity applicability of the results, as well as on the process used. Figure 1 shows the flowchart of five step concept generation method.

Clarify the problem: This step consists of developing a general understanding about the problem and then breaking the problem down into sub-problems if necessary. As stated above, the challenge was to "design a compact and safer assembly fixture with better structural rigidity and levelling mechanism". The main purpose of the fixture is to hold and position the column while assembling parts over it like head support, guide ways, accumulator, ball screws, counterbalancing cylinder, motor for ball screw etc and to support while tilting it to vertical position for the assembling it in the machine. Based on the above problem the needs of the fixtures are identified.

- The fixture should be compatible with columns of all size of machines.
- To use the same fixtures for both preassembly and tilting purposes.
- The fixture should require lesser set up time.
- The fixture should be rigid and safer for both operations.
- The fixture should be easy to assemble and maintain.
- The fixture should be compact for providing ease for shop floor person in assembly operations.

These basic needs were subsequently translated into target product specifications. The target product specifications include the following:

- The fixtures should carry a minimum of 2000 kg on each side of the back supports.
- The Levelling mechanism requires a minimum height adjustment of +/- 40mm.
- Angle to which the column has to tilt is 90^{O}.
- The height of the fixture should not be more than 800mm.
- The required gap between two back fixtures should be more than 1200mm.
- The column should have a minimum clearance of 300mm with floor after tilting.

The whole problem is decomposed into sub-problems (Fig. 2). The goal of decomposition is to divide a complex problem into simpler problems such that these simpler problems can be tackled in a focused way. This problem statement can be divided in two sub problems i.e. a mechanism required to lift the level the column height and another mechanism which is used to tilt the same.

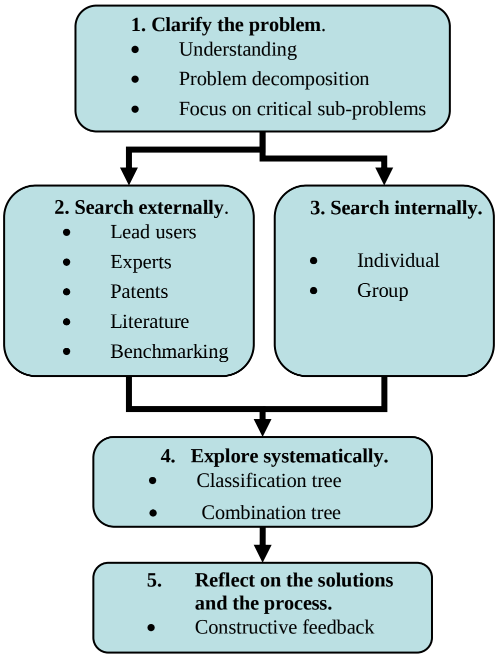

Fig 1. Flowchart of five-step concept generation method

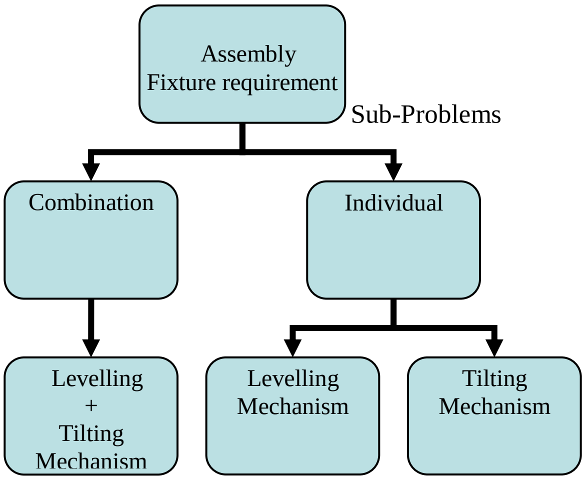

Fig 2. Flowchart showing decomposition of Assembly fixture requirement

1) Search Externally: External search is aimed at finding existing solutions to both the overall problem and the sub-problems identified during the problem clarification stage. External search occurs continually throughout the development process. Some of the ways used to gather information from external sources are expert consultation, patent searches, literature searches and competitive benchmarking. In this project work patent searches and literature searches have been carried out.

2) Search Internally: Internal search consist of individual and group sessions. It is the use of personal and team knowledge and creativity to generate solution concepts. In this project work internal search was carried out by consulting various department experts and by conducting group sessions. Present company technology is also studied as a part of this step.

3) Explore systematically: As a result of internal and external search activities many concepts have been conceived. Managing these large numbers of solutions is a difficult task. There are two specific tools in product design for addressing this problem. They are:

a) Concept classification tree: This is used to split the entire area of possible solutions into several distinct classes which will assist in comparing and trimming. The concept classification tree for levelling mechanism and tilting mechanism are as shown below

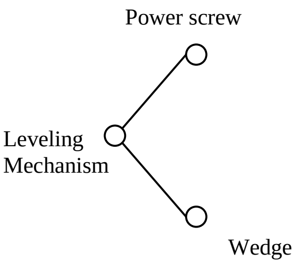

Fig 3. Concept classification tree for column levelling mechanism

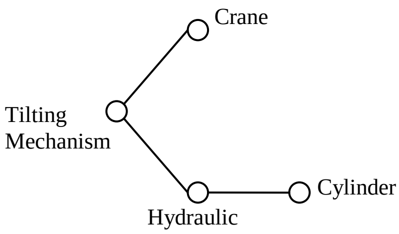

Fig 4. Concept classification tree for column tilting mechanism

b) Concept combination table: It provides a way to consider combinations of solution fragments systematically. The columns in the table correspond to the sub-problems identified previously. The entries in the table I correspond to solution fragments for each of the assembly sub-problems derived from external and internal search.

TABLE I CONCEPT COMBINATION TABLE

Leveling mechanism	**Tilting Mechanism**
Wedge	Crane
Power screw	Hydraulic cylinder

With the reference to above concept combination table four different concepts are developed which are explained below.

- *Wedge + Hydraulic cylinder:* The concept makes use of fluid power for operating the hydraulic cylinder for giving the pull for tilting the column by supporting on the fixture. Here the levelling for the column at each supports is done by using wedges. Two cylinders are provided for giving the required pull.
- *Wedge + Crane:* This concept is almost similar to concept 1 except that it is uses of cranes for tilting the column.
- *Power screw + Hydraulic cylinder:* This concept uses a power screw in the fixture for the levelling mechanism. For tilting the column on the fixture, hydraulic cylinders are used. Two cylinders are used for giving the required pull.
- *Power screw + Crane:* In this concept, the power screw provided in the fixture is used for levelling the column height before starting the assembly operations. Also crane is used for tilting the column from one end with the other end supported on the fixture.

4) Reflect on the solutions and the process: The reflection process should be carried out throughout the concept generation stage. In this step questions to ask include:

- Are there alternative ways to decompose the problem?
- Have external sources been thoroughly pursued?
- Are there any alternative function diagrams?

In this step problem decomposition & solutions to the sub-problems are verified. Each and every step is cross checked so as to find every alternate solution to the problem.

C. Concept selection

This is the process of evaluating concept with respect to operator needs and other criteria, comparing the relative strengths and weakness of the concepts, and selecting one or more concepts for further investigation, testing, or development. This step consists of two main stages. The first stage is called concept screening and the second stage is called concept scoring. As there are only 4 concepts, concept scoring method can be used directly.

Concept scoring: Concept scoring is used when increased resolution will better differentiate among competing concepts. In this stage determination of the relative importance of the selection criteria and focuses on the more refined comparisons with respect to each criterion is done. The concepts that have been identified for analysis are entered on top of the matrix. The selection criteria are entered at left-hand side of the matrix. After criteria are entered some importance weights are assigned to each criterion. Rating of concepts is a very important in concept scoring stage. Because of need for additional resolution to differentiate between competing concepts, a finer scale is used. In this step a five point scale is used to rate the criterion.

Relative Performance	Rating
Much worse	1
Worse	2
Not bad	3
Better	4
Much better	5

Once the ratings are entered for each concept, weighted scores are calculated by multiplying the raw scores by criteria weights. The total score for each concept is sum of the weighted scores:

$$S_j = \sum_{i=1}^{n} r_{ij} w_i$$

Where

r_{ij} = raw rating of the concept *j* for *i*th criterion

w_i = weighting for *i*th criterion

n = number of criteria

S_j= total score for concept *j*

TABLE II
CONCEPT SCORING TABLE

			Concepts							
			Concept-1		Concept-2		Concept-3		Concept-4	
SL No	**Selection criteria**	Weight (%)	Rating (0-5)	Weighted score	Rating (0-5)	Weighted score	Rating (0-5)	Weighted score	Rating (0-5)	Weighted score
1	Cost	20	3	0.6	4	0.8	3	0.6	4	.8
2	Ease of operation	15	2	0.3	3	0.45	3	0.45	5	0.75
3	Compactness	6	2	0.12	3	0.18	2	0.12	4	0.24
4	Load handling capacity	30	2	0.6	3	0.9	2	0.6	4	1.2
5	Assembly of fixture	8	3	0.24	3	0.24	3	0.24	3	0.24
6	Overall weight	6	2	0.12	4	0.24	2	0.12	4	0.24
7	Life of the system	8	3	0.24	4	0.32	3	0.24	3	0.24
8	Safety	7	2	0.14	3	0.21	3	0.21	4	0.28
	Total Score		2.36		3.34		2.58		3.99	
	Rank		4		2		3		1	
	Continue?		No		No		No		YES	

III. Design specifications and CAD Modeling

A. Fixture

The 3D model of the fixture is shown in the Fig. 5. Totally 3 fixture are used for supporting the column for the assembly operations. The column weighs 4000 kg, so the load acting on the fixture is 13333N. Tilting of column is done by supporting only on the two back fixtures, so load acting on each of the back fixture is 20000N. A V-locator is used for locating the rod which holds the column. Top clamps are provided for resisting any kind of plays. The fixture is fixed with the ground using anchor bolts. A structural steel tube is used which will act as the main support is provided with guide ways for the guiding rods while operating the power screw. A flange welded at the down end of tube will slide over the power screw nut during leveling operations. A plate is attached on the screw head, which will guide the tube from inside and also resist from dynamic loads. Ribs are provided at the top and base plate for giving strength for welded joints.

B) Power screw

A square threaded power screw is used with the following dimensions.

Screw : Major diameter = 110mm
Minor diameter = 98mm

Nut : Major diameter = 110.5mm
Minor diameter = 98mm,

Pitch : 12 mm

Fig 5. Single fixture

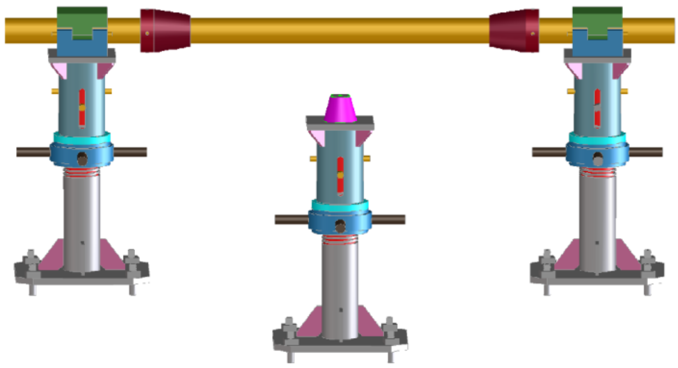

Fig 6. Complete fixture arrangement

IV. STRUCTURAL ANALYSIS OF THE FIXTURE

ANSYS is general-purpose Finite Element Analysis (FEA) software package. Finite Element Analysis is a numerical method of deconstructing a complex system into very small pieces (of user designed size) called elements. The software implements equations that govern the behavior of these elements and solves them all; creating a comprehensive explanation of how the system acts as a whole.

The ANSYS Workbench environment is an intuitive up-front finite element analysis tool that is used in conjunction with CAD systems and/or Design Model. ANSYS Workbench is a software environment for performing structural, thermal, and electromagnetic analyses. The Workbench focuses on attaching existing geometry, setting up the finite element model, solving, and reviewing results.

Software used	:	Ansys workbench 14.5
Analysis	:	Static analysis
Coordinate system	:	Global coordinate system
Type of support	:	Fixed support
Type of load	:	Force

A. Analysis steps used for the fixture

1) *Importing the 3D model* **:** The 3D model of the fixture set was imported in IGES format.

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2) *Generated ansys model geometry*

The Ansys geometry of the fixture set is shown In the Fig. 8

3) *Meshing*

Type of mesh	:	Tetrahedral element mesh
Quality of mesh	:	Fine
No of elements	**:**	26008
No of nodes	**:**	57945

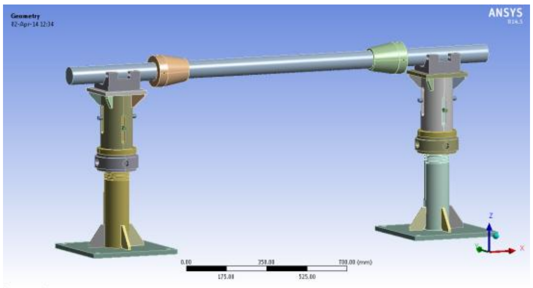

Fig. 8

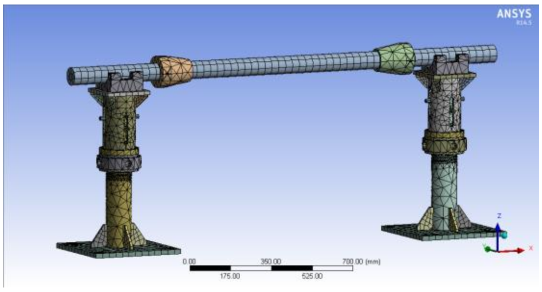

Fig. 9 Meshed view

4) *Settings for analysis*

Type of contacts between parts: Bonded and No separation

Material properties

Young's Modulus	2.e+005 MPa
Poisson's Ratio	0.3
Density	7.85e-006 kg/mm³
Tensile Yield Strength	240. MPa
Compressive Yield Strength	240. MPa
Tensile Ultimate Strength	420. MPa

5) *Mentioning loads and supports*

Load applied	**:**	20000N each at both ends
Fixed support	**:**	Base plate bottom of the fixture

Load applied **Fixed support**

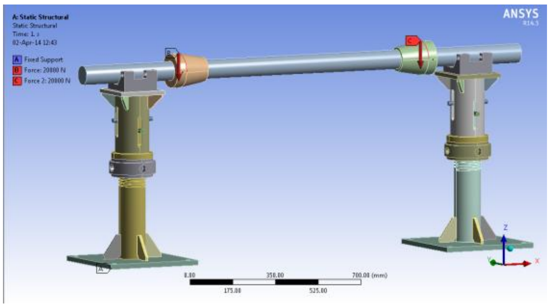

Fig 10

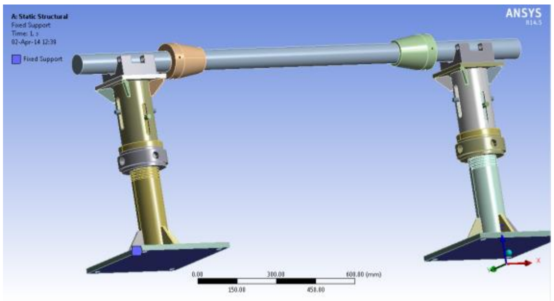

Fig 11

6) *Solve*

Equivalent stress

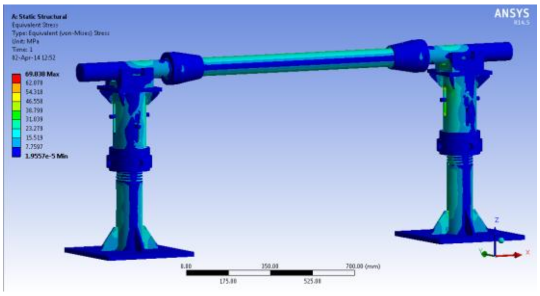

Fig 12

Total deformation

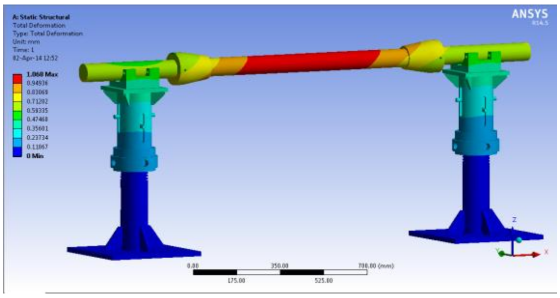

Fig 13

Safety factor

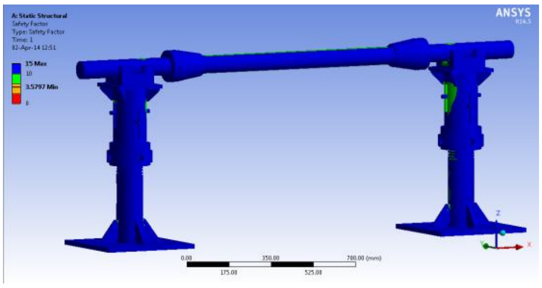

Fig 14

B. Analysis Results

Table III

Terms	Values
Maximum stress	69.83 Mpa
Maximum deformation	1.068 mm
Safety factor	3.58

V. CONCLUSIONS

- The existing method of two different setups for assembling the column was replaced using the new proposed design of fixture which needs only one setup.
- The new proposed fixture design shows a reduction of 0.64 m2in the floor space requirement.i.e. an 80% reduction in the space required compared to the existing method.
- Structural analysis of the fixture shows the maximum deformation to be 1.06 mm and maximum equivalent stress to be 69.83 MPa. These values are within the safe limit for the steel material.

- The comparison of the setup time required between the existing and new design shows a saving of 102 min i.e. a 65.8% reduction in the setup time required for the new design compared with the existing method.

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