

Need and Requirements of a Fixture for Planet Carrier- A Case Study

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ABSTRACT: In the dawn of manufacturing a new work piece, various constraints are to be studied and evaluated. While machining under arduous conditions and particularly in mass production, the use of a jig and a fixture is proven to be a viable solution to reduce the fatigue of workers, provide high strength, increases accuracy and easy interchangeability whenever required. In the case of planet carrier, its peculiar design has not yet inspired designers to design and manufacture a fixture whilst it is still in machining. This paper defines the need and the requirements that are to be instilled in the fixture for a planet carrier and in culmination, this fixture will decrease cycle time required for loading and unloading of a part, escalates production rate, reduces accidents, will be highly versatile and reliable and most importantly, decreases the cost of production.

KEYWORDS: Fixture; Design; Planet Carrier; Computer Aided Designing; Vertical Machining; Productivity; machinability.

I. INTRODUCTION

Planetary gears system consists of one or more outer gears (planet gears), revolving about a central gear (sun gear). Normally, the planet gears are mounted on a movable arm or carrier which may rotate relative to the central gear. They also incorporate the use of an outer ring gear (annulus), which meshes with the planet gears.

Planetary gears are typically classified as

- 1) Simple planetary gears
- 2) Compound planetary gears.

Simple planetary gears have one sun, one ring, one carrier, and one planet set. Compound planetary gears involve one or more of the following three types of structures. Firstly, a meshed-planet where there are at least two more planets in mesh with each other in each planet train. Secondly, a stepped-planet where there exists a shaft connection between two planets in each planet train and thirdly a multi-stage structure where the system contains two or more planet sets. Compared to simple planetary gears, compound planetary gears have the advantages of larger reduction ratio, higher torque-to-weight ratio, and more flexible configurations.

The advantages of planetary gear trains are:

- 1) Higher torque capacity i.e. split in different gear which are meshed together.
- 2) Reduced noise and Vibration
- 3) Low wear and tear due to even distribution of load
- 4) Lower weight
- 5) They occupy less space due to small sizes
- 6) Improved efficiency of the planetary design
- 7) As they weigh 60% and half the size of a conventional gear box, they are often misjudged as frail. But they are comparatively much stronger than other gear casings

The planetary gear trains have a wide range of applications listed below:

- 1) Automobile
- 2) Power transmission
- 3) Power generation

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- 4) Sugar industry/Mills
- 5) Oil industry/refinery
- 6) Food Industry
- 7) Bulk material handling
- 8) Marine and Defence applications
- 9) Clocks and many other miscellaneous small and big applications.

A fixture is a special purpose tool which facilitates production (machining, assembling and inspection operations) when work pieces are to be produced in mass production. Study of components, geometric models of components, step by step design calculation, selection of tooling material and solid modelling of tool will lead us to optimal and feasible fixture design. High-performance, precision, accuracy and interchangeability are critical elements of a fixture. In culmination, a fixture decreases cycle time required for loading and unloading of a part, escalates production rate, reduces accidents, are highly versatile and reliable and most importantly, decreases the cost of production.

II. MANUFACTURING OF PLANET CARRIERS: PRESENT SCENARIO AND ASSOCIATED PROBLEMS

The manufacturing of planet carriers is carried out from the basic steps right from the beginning that is from the selection of materials, to the final inspection inside the company premises by their highly skilled engineers and workforce.

The sequence of operations is discussed later on in this section. Whilst manufacturing planetary carriers, the parts are divided into 3 parts and manufactured separately at first and then fabricated and machined to give the final product. The description of part, material used commonly and the quantity used are specified in the Table 1. The parts as named by the company is given in the table given below:

Table 1 Parts of Planet Carrier

ITEM NO.	DESCRIPTION	MATERIAL	QTY
01	FORGING FOR PLANET CARRIER FLANGE-1	42CrMo4-H&T	01
02	FORGING FOR PLANET CARRIER FLANGE-1	42CrMo4-H&T	01
03	PROFILE PLATE	E-250 B,IS:2062	03

FORGING FOR PLANET CARRIER FLANGE-1: This is the bottom part of the planetary carrier. It is manufactured by forging to give it high strength and gives better responses to heat treatment. It takes a total of 2-3 days to manufacture as a part. It is made from a high grade metal 42CrMo4 that provides a great deal of mechanical and thermal properties. The flange-1 is generally similar in almost all the planet carriers as shown exactly in the Creo model in the 3 views-slanted view, top view and front view respectively in fig. 1. The machining operations such as drilling, boring and grinding is done after the whole part is fabricated together via welding i.e. after it is attached as a whole with the upper flange via the profile plates. Only the hollow part in between the cylinders is manufactured whilst forging.

FORGING FOR PLANET CARRIER FLANGE-2: This is the top part of the planetary carrier. It is manufactured by forging to give it high strength and gives better responses to heat treatment. It takes a total of 2-3 days to manufacture this part. It is also made from a high grade metal 42CrMo4 that delivers a great deal of mechanical and thermal properties. The flange-2 is generally similar in almost all the planet carriers as shown exactly in the Creo model in the 3 views-slanted view, top view and front view respectively in fig. 2.

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The machining operations such as drilling, boring and grinding is done after the whole part is fabricated together via welding i.e. after it is attached as a whole with the bottom flange via the profile plates. Only the hollow part in between the cylinders is manufactured whilst forging.

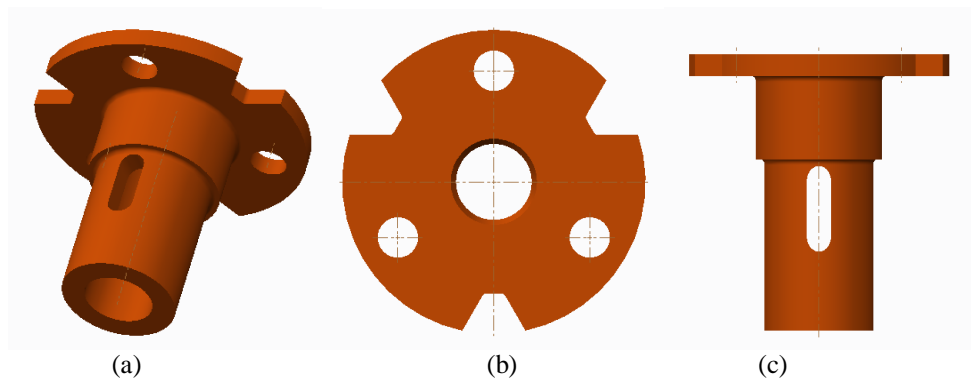


Fig. 1. Creo model of flange-1 (a) slanted view (b) top view (c) front view

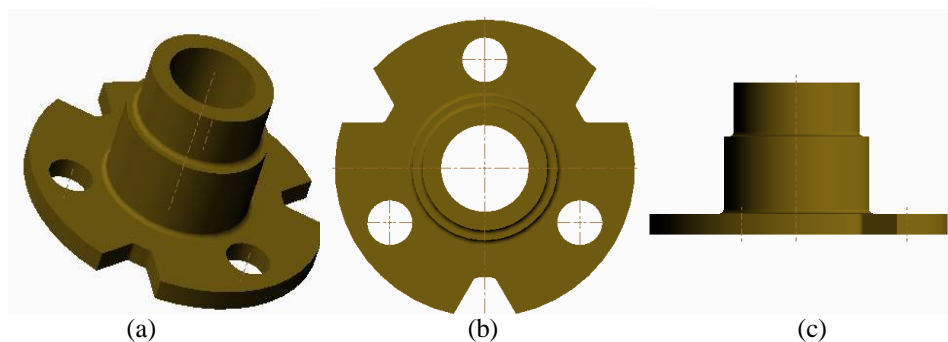


Fig. 2. Creo model of flange-2 (a) slanted view (b) top view (c) front view

PROFILE PLATES: As the name suggests, these are plates that welds the planet carrier flange-1 and the planet carrier flange-2. They are V-shaped that provide uniform load absorption i.e. provide maximum support for stresses as that are applied during and after manufacturing the whole planet carrier in accordance with their peculiar shape. These plates are made either by casting or welding. They are made from chemical composition of E-250 B, IS: 2062. The profile plates are shaped similar to the ones shown in fig. 3 which shows the creo model of the slanted view, top view and front view of the profile plates.

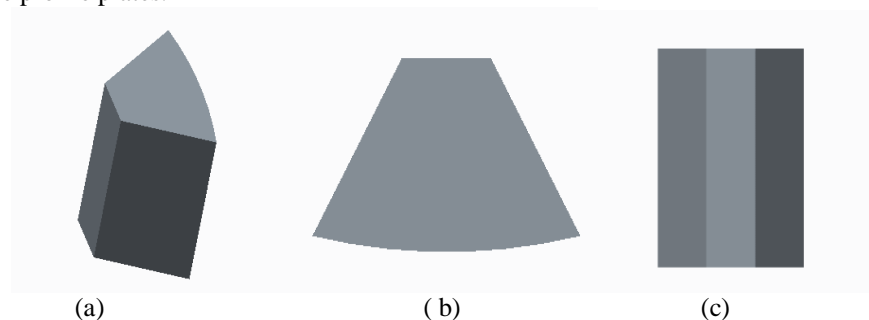


Fig. 3. Creo model of Profile Plates (a) slanted view (b) top view (c) front view

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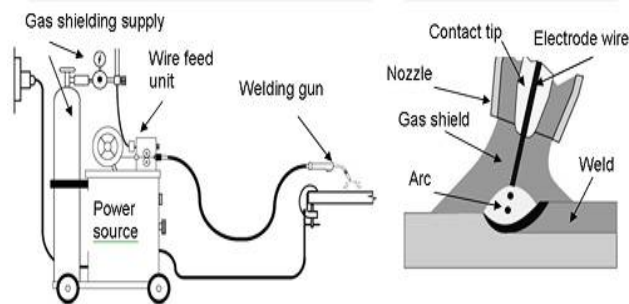


Fig. 4. Setup of with Metal Inert Gas Welding

The profile plates are welded together with the planet carrier flange-1 and planet carrier flange-2 with Metal Inert Gas Welding (MIG Welding). Metal Inert Gas Welding is an electric arc welding process that fuses together the parts to be welded (profile plates with the planet carrier flange-1 and planet carrier flange-2) by heating them with an arc between a solid metal electrode and the workpiece. The filler metal is obtained from melting of the electrode wire, which is fed continuously into the arc by the welding equipment. The shielding is provided from an externally supplied gas or gas mixture. A diagram of the exact setup is shown in the figure 4 above. The inert gas used in this situation is CO₂ (carbon-dioxide) because of its better cooling and reduce atmospheric contamination. The torch produces an oxy-acetylene flame. It uses a filler rod FC42 due to its fine properties and is economic. The flame produced is at a mandatory length of 5mm long and can be as long as 10mm. The main advantage of this welding process is faster operation, easy availability and affordability. The main problem faced during this operation is the process heating up takes a lot of time. The Table 2 below depicts the various operations that are carried out to manufacture the planet carrier and the time taken to machine them along with their setup time (cumulative).

Table 2 Sequence of machining operations

Sr.No	OPERATIONS	TIME CONSUMED (in hours)
1	Forging pre-machining	72
2	Forging cut	3
3	V-preparation for welding	8
4	Preheating	2
5	Welding	8
6	Post-Treatment	1
7	Grinding	4
8	Preheating	2
9	Welding	2
10	Grinding	0.5
11	Stress relieve	24
12	Shot blasting	24
13	Painting	24
14	Marking	1
15	Plug boring	5
16	Turning with grinding allowance	6
17	Grinding	6
18	Boring	8
19	Keyway milling	3

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The gear when finally fabricated and machined properly is shown in the figure 4. The figure 4 below are Creo models of the planet carrier in its exploded view, front view and top view. A very peculiar design of a gear discussed in this paper is the planet carrier, which is a form of an epicyclic gear train. Due to its atypical design, it is difficult to machine the planet carrier. Presently, in all the basic machining operations that are carried out on the planet carrier, the engineer faces a lot of glitches in setting up of the work piece. Due to unavailable fixtures for these peculiar kind of work pieces, a non-conventional setup is preferred by the engineer. The use of V-blocks, clamps and screws for holding and supporting of the work piece in a horizontal setup of the workpiece on the Horizontal Machining Centre hints to a failure of a lot of machining constraints and is also highly time consuming activity. In endeavouring to abate all the problems faced during the use of non-conventional tools, this paper shows the need for a design of a fixture that can eliminate all the strenuous preceding tasks and enhance the production rate and operations altogether. The following are the problems that occur during machining planet carriers in the existing method:

- Balancing of top and bottom part is an arduous task
- Centering the work piece consumes a lot of time
- Vibrational and mechanical errors are high
- Offset while operation
- High skill required
- Consumes a great amount of time (3-4 hours minimum)

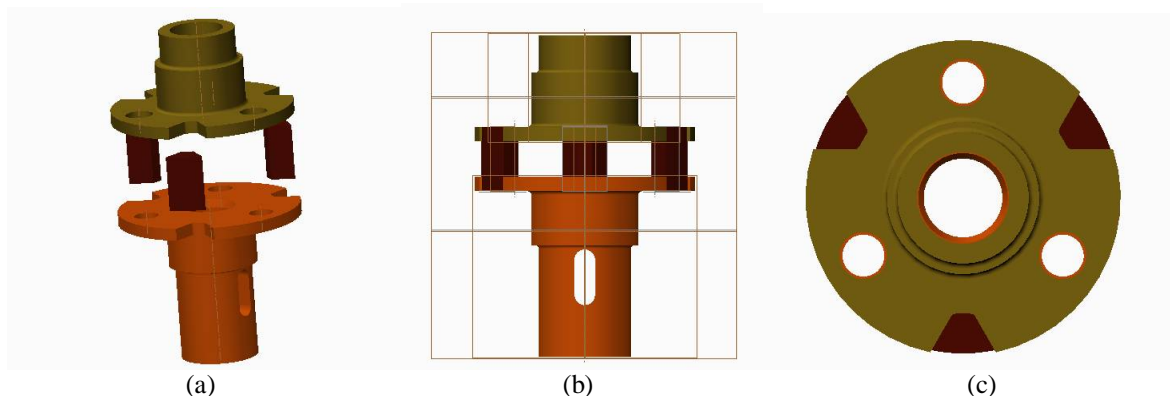


Fig. 4. Creo model of planet carrier (a) exploded view (b) front view (c) top view

III. PROPOSED METHODOLOGY

While designing this fixture, a good number of literature and titles written on the subject by renowned authors are to be referred. All findings and conclusions obtained from the literature review and the interaction with fixture designers are used as guide to design the required fixture. Various areas related to design of fixture like machining fixture knowledge, optimizing workpiece setups, modelling of forces, improving workpiece location and high efficiency tools are already been very well described by various renowned authors. Makwana and Gosavmi have found that there are different steps and approaches are available for designing the fixture. Among those geometry method (3-2-1 principle) and it is very useful for the complex fixture design though it is the basic principle of the fixture design [1]. Hunter, R., Vizan, A., Perez, J., Rios J Proposed the methodology for design of a fixture which includes the realization of two stages [2]. An important characteristic of a workpiece-fixture system is that locators are passive elements and can only react to clamping forces and external loads, whereas clamps are active elements and apply a predetermined normal load to the surface of workpiece to prevent it from losing contact with the locators [3]. X.P Li, A.Y.C Nee, Y.S Wong, H.Q Zheng developed a theoretical model for forces in milling based on a predictive machining theory and the mechanics of milling [4]. J. C. Trappey, C. R. Liu published a review of fixture-design research out of which most of it was carried out in the 1980s. The major topics reviewed are the fixturing principles i.e. supporting, locating and clamping, then

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automated fixture design i.e. configuration, assembly and verification, and fixture hardware design i.e. dedicated, modular and electric/ magnetic types [5].

The process of fixture design generally works out in three phases: planning, design and assembly. In the initial stage, that is the planning phase, the need and the configurations of the fixture are determined. For example, only if the conventional method, that is when machining without the use of fixture proves to be a tedious prolonged activity and the introduction of the fixture can reduce this, only then the need to build a fixture is to be established, otherwise it proves to be a waste of resources. The need and characteristics may also include the about the decision making on the sectors of material availability, machine resources, material handling, facilities planning, degree of automation and quality specifications. Bhavya R. Gajjar and Saurin Sheth presented a paper, Design and Automation in Back Plug Press Fitting Process of Ball Pen Assembly in which after realizing the need to automate and simplify the process they worked on the future and productivity enhancement of the back plug press fitting process of ball pen assemblies [7]. Saumil Desai and Saurin Sheth published a Study and Proposed Design of Dual Faceplate Centrifugal Casting Machine for manufacturing of turbine bearing which designates the detailed analysis of the system and the process which is simplified from the predecessor techniques [9]. In the second stage, that is the design phase, detailed analysis is to be carried out on the aspects of locating, clamping and supporting of the workpiece. The design stage should also keep in mind the economical aspect of the fixture. Gajjar B and Sheth S presented their work in Investigation of Automation Strategy and Its effect on Assembly Cost: A Case Study on Ball Pen Assembly Line which focused on the main goal of reducing the cost of production which is one of the main stanchions of today's industrial revolution [10]. In the final stage, that is the assembly stage, the fixture is assembled by combining its different parts together. This can be performed manually or automatically using machines. Hardik Gangadia, Saurin Sheth and Purvi Chauhan have worked on the simple cases of Design & Modelling of Special Purpose Equipment for Shell- Diaphragm Welding in Conveyor Pulley in which they automated the whole operation by simple mechatronics approach which can be even be a significant base work for the fixture [8]. Vaghasiya M, Moradia H, Nayi R, Sheth S and Hindocha B have published their work on Modelling of an automatic positioner- A mechatronics approach, which is also a brilliant example of the use of mechatronics to automate and simplify the process of manufacturing [11].

To design a fixture for the planet carrier, a simple and efficient design methodology is stated below:

- 1) Define and evaluate the current scenario.
 - The basic step is to profoundly understand the current scenario i.e. the fixture employed by the manufacturer and the problems they face during the operations.
- 2) Study and analyse the sequence of operation of planetary carriers.
 - A complete study on the processes and the sequence of operations performed in the manufacturing of planetary carriers from the beginning i.e. forging, to the final finishing is to be carried out.
- 3) Identify the problem during boring in planetary carriers.
 - Identifying the majorly recurring loss, and troubleshooting the problem due to which the loss is created.
- 4) Study of Literature Review.
 - Study about Planetary carriers.
 - Study about Fixture Design concepts.
 - Study about Computer Aided Designing Software's.
 - Study of various locating principles, such as 3-2-1 principle.
- 5) Prepare a conceptual Fixture Design.
 - A rough outline is prepared after brainstorming various ideas.
- 6) Development of Design.
 - Further using CAD/Creo various models of modular fixture are to be prepared. This will provide a range designs for selecting the optimum one.
- 7) Improve design as per analysis.

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IV. FIXTURE SPECIFICATIONS AND REQUIREMENTS

The workpiece in subject is the planet carrier. The peculiar design of this planet carrier has certain requirements to be kept in mind before designing the fixture. The following are the specifications and requirements that the fixture must display:

- 1) The planet carrier has a long shaft at the south end of the design. At most times the shaft has undergone vigorous heat treatments and machining process up to grinding and even surface finishing's. The designer must keep in mind that this shaft is not compromised with.
- 2) Planet carriers are heavy most of the times, and they are difficult to handle due to their intricate shape also. So, the mounting and ejecting of the planet carrier should be done safely and easily without any glitches in the operations.
- 3) There can be vast variations in the diameters of the planet carriers and to handle such large variations, a proper work holding mechanism is to be developed. These variations in the diameters can range from 200centimeters to 1000 centimetres.
- 4) The size of the fixture should be compact and if possible a fixture that can be assembled by joining the small parts in the fixture assembly can show optimum viability.
- 5) The material to be used in the fixture should be cheap and durable, but also high in mechanical properties. This is because it should be able to withstand the planet carrier's disproportionate load and machining forces when applied.
- 6) The planet carrier is deep, long and hollow and the design should be such that the operator knows the relative position that is to be machined and also have a clear view when the machining operation is being conducted.
- 7) The planet carrier's upper flange should be held sturdy so as to provide firm grasp for machining, otherwise there is a high probability of offset.
- 8) The fixture should be constructed such that it allows vertical machining than horizontal machining so as to reduce specific problems of offsetting, high setup time and other miscellaneous related complications.
- 9) A self-centering fixture is a mandatory prerequisite.
- 10) It should also provide high easy and fast interchangeability between the workpieces.
- 11) Other trivial fixture design requirements are also be considered.

V. CASE STUDY

- To understand the advantages of the fixture to be designed, let us take a case study (a hypothetical case):
Case Study: If a manufacturer acquires an order to manufacture 20 planet carriers. Now, if he acquires 20 planet carriers in a month, he therefore may be willing to manufacture 240 planet carriers in a year. Let us assume he is preparing to enlarge the 6 holes in the planet carrier via boring. For a single setup without the fixture designed, he may take an approximate of 180 minutes to setup the work piece. Hence, if he does that for every 20 of them acquired in a month and every 240 he may get in a year, he is prone to a huge time loss just during setup, let alone the losses that occur during machining. The calculated ingested time is a whopping 43,200 minutes.
Now, if the manufacturer incorporated this fixture designed he will be able to setup the time of the workpiece to just a mere 45 minutes, that in culmination of a fiscal year can be accounted to only 10,800 minutes. The time reduced via this case study is astonishingly "75 percent".
- Saving time is just an additional way of saving money. This is possible because the manufacturer can now acquire 75 percent more orders owing to the time saved. This increases the revenue and hence increases their creditability and therefore the manufacturer proliferates.

VI. CONCLUSIONS AND FUTURE SCOPE

- The fixture can be employed for vertical machining and the operations like boring, internal threading, broaching and drilling can be performed.

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- Not only can this be used to machine the planet carrier but also machining a circular workpiece with different dimensions and shapes can be incorporated in this fixture assembly.
- Another manufacturing process, such as welding can also be performed with the help of this fixture.
- Attaching the planet gears and other miscellaneous parts can be made easy.
- The need for a skilled worker to operate the fixture is eliminated. There will be no need for more than one person to set up the fixture and analyze it continuously in each step.
- There is an utter need to discover new self-centering principles.
- The fixture to be designed can be enhanced by introduction of new self-centering principles and automating the fixture with the help of a pneumatic and hydraulic assisted mechanisms.

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