International Journal of Engineering Inventions
e-ISSN: 2278-7461, **p**-ISBN: 2319-6491
Volume 2, Issue 3 (February 2013) PP: 10-21

Design, Modelling & Analytical Analysis of Rotary Fixture for CNC with an Approach of Computer Aided Mass Balancing Method

N. P. Maniar[1], D. P. Vakharia[2]
[1]Department of Mechanical Engineering, Dharmsinh Desai Univeristy, Nadiad, India
[2]Department of Mechanical Engineering, Sardar Vallabhbhai National Institute of Technology, Surat, India

Abstract:- Various areas related to fixture are already been described by renowned authors, still there is an urgent need to apply all these research works to an industrial application. This paper presents design and development of rotary fixture for machining real industrial component - Flow TEE body of petroleum refinery. Actually HMC is the best solution for performing the required operations, but HMC costs around 12.5 million rupees whereas CNC turning centre costs only about 2.5 million rupees. A fixture is designed with the help of which these operations can now be performed on CNC turning centre and hence 10 million rupees are saved in installation cost. Methodology for mass balance of rotary fixture developed by investigators mostly act as post-mortem tool; calculating unbalanced mass after fixture is manufactured. In the present work, a pre-mortem tool is developed to predict unbalanced mass well before manufacturing. The present research also proposes three alternate methods for mass balancing of rotary fixture using Pro/Mechanism. Analytical calculations is also covered. The paper sets the classical example of integrated approach of design for manufacturing.

Keywords:- CNC, Computer Aided Mass Balancing Method, Design, mass balancing, rotary fixture

I. INTRODUCTION

The machine tool industry has undergone sufficient changes as the requirement of user engineering systems changed; first it started with the manufacture of basic general purpose machine tools. These machines though offered higher flexibility were not suitable for mass production owing to longer set up times and the tedious adjustments of machine and tools besides requiring highly skilled operators. With growing need of fast production to meet the requirements of industry, mass production machines are conceived. Hydraulic, tracer control machine tool, special purpose automatic and semi-automatic machines were introduced with the advancement of technology. These machines were highly specialized but inflexible. The use of these machines was with a success for mass production and they have considerably reduced the production costs by way of reduced machining times and labor costs. Because of inflexibility these machine tools could not however be adopted by units involved in small lot and piece production.

Because of the above, great need is felt for tools that could bridge the gap between highly flexible general purpose machine tools (which are not economical for mass production) and highly specialized, but inflexible mass production machines. Numerical control machine tools with proper fixture set up have to take up this role very well. And this has excited this research work on design and development of rotary fixture for CNC. The fixture designing and manufacturing is considered as complex process that demands the knowledge of different areas, such as geometry, tolerances, dimensions, procedures and manufacturing processes. While designing this work, a good number of literature and titles written on the subject by renowned authors are referred. All findings and conclusions obtained from the literature review and the interaction with fixture designers are used as guide to develop the present research work. As stated by Koji Teramoto, Masahiko Anasoto and Kazuaki Iwata [1], Fixturing Plan (FP) and Machining Plan (MP) are mutually dependent. Implicit to this conclusion, paper coordinates MP and FP by coupling a fixture design with manufacturing considerations and mass balancing. For this research, a relevant issue when considering requirements, taking this as a general concept, is to make explicit the meaning of two main terms: Functional Requirement (FR) and Constraint (C) [2]. Functional Requirement (FR), as it stated by different authors, 'represents what the product has to or must do independently of any possible solution'. Constraint (C) can be defined as 'a restriction that in general affects some kind of requirement, and it limits the range of possible solutions while satisfying the requirements'. Though some contributions have been made in several areas related to design of fixture like knowledge model for fixture design process, workpiece location, computer aided fixture design, fixture analysis under dynamic machining etc. [3-8], but there is a great deal of urgency and importance to couple all these research works to an industrial application. This paper reviews all these research works and transforms the theoretical knowledge of fixture design to practical application.

The balancing of mechanisms is motivated by continuous interest machine designers express in the solution of problems concerning prevention of noise, wear and fatigue generated by the transmission of unbalanced shaking forces and shaking moments to the frames and foundations of machines. It generally confines itself to the shaking force and shaking moment balancing, full or partial, by internal mass redistribution or counterweight addition. However, the complete shaking force and shaking moment balancing problem is very complicated. Often in practice, the problem of mass balancing is limited by full force balancing and partial moment balancing [7]. Methodology for mass balance of rotary fixture developed by investigators mostly act as post-mortem tool; calculating unbalanced mass after fixture is manufactured. In the present work, a pre-mortem tool is developed to predict unbalanced mass well before manufacturing. Step by step procedure for mass balancing of fixture is proposed with the innovative approach of use of Creo Elements/Pro 5.0. The present research proposes alternate methods of IV Quadrant, VIII Quadrant and VIII Diamond Quadrant Computer Aided Mass Balancing Method (CAMBM) for rotary fixture.

The important details of the part and fixture are included in each fixture design section for clarifying doubts in addition to component drawing & fixture drawing. The research work includes the 3D assembled & exploded view of fixture using Creo Elements/Pro 5.0. Fixture is mass balanced using Pro/Mechanism. The object of work presented here is to develop the study and to provide the optimum conditions of design and development of rotary fixture for CNC.

II. DESIGN & DEVELOPMENT OF ROTARY FIXTURE

2.1 Statement of Problem

"Design & development of rotary fixture for machining flow TEE body on CNC turning centre. The operations to be performed are front facing, outside diameter turning, grooving, boring and back facing. The fixture being rotary in nature has to be mass balanced."

2.2 Component details

The methodology proposed for design of a fixture includes the realization of two stages. The first stage represents the knowledge of the objects like part geometry, machining process, functional and detailed fixture design, and fixture resources. The second stage describes the inference process (design and interpretation rules) needed to obtain a first solution for the machining fixture [3]. As a part of first stage, component geometry is discussed here [Fig. 1-3].

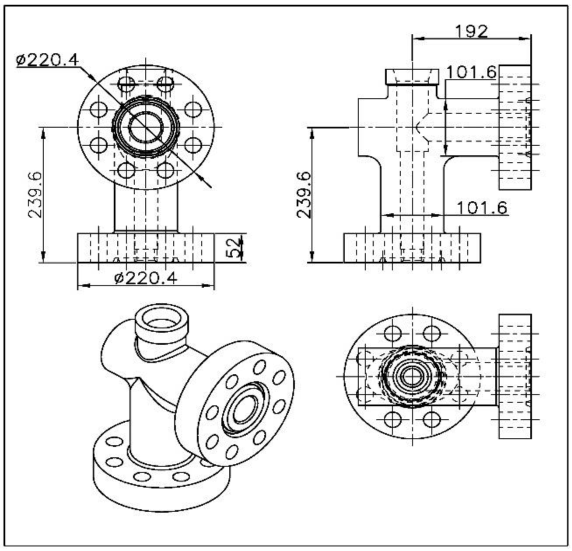

Figure 1. Finished Component Drawing

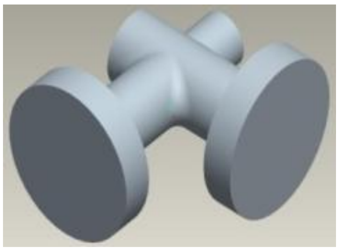
Figure 2. 3D view of raw material of component

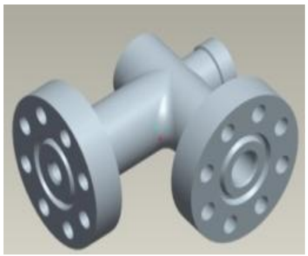
Figure 3. 3D view of finished part

The component is Flow TEE body, made up mild steel, weighing 46.5 kg and is one of the components of petroleum refinery. The component is used as a joint or coupler for pipes through which petroleum liquid products flow and get mixed. The component in raw material form is forged, proof machined with 3 mm machining allowance on conventional lathe with 24 inch swing over diameter. The operations to be performed on component, using designed fixture set up, are front facing, outside diameter turning, grooving, boring and back facing.

2.3 Locating and clamping

In machining, work holding is a key aspect, and fixtures are the elements responsible to satisfy this general goal. Usually, a fixture solution is made of one or several physical elements, as a whole the designed fixture solution must satisfy the entire FRs and the associated Cs. Centering, locating, orientating, clamping, and supporting, can be considered the functional requirements of fixtures. In terms of constraints, there are many factors to be considered, mainly dealing with: shape and dimensions of the part to be machined, tolerances, sequence of operations, machining strategies, cutting forces, number of set-ups, set-up times, volume of material to be removed, batch size, production rate, machine morphology, machine capacity, cost, etc. At the end, the solution can be characterized by its: simplicity, rigidity, accuracy, reliability, and economy [2]. Workpiece location in a fixture is significantly influenced by localized elastic deformation of the workpiece at the fixturing points. These deformations are caused by the clamping force(s) applied to the workpiece. For a relatively rigid workpiece, the localized elastic deformations cause it to undergo rigid body translations and rotations which alter its location with respect to the cutting tool. It is therefore important to minimize such effects through optimal design of the fixture layout [4].

Centering, locating, orientating, clamping, and supporting, can be considered the functional requirements of fixtures. In terms of constraints, there are many factors to be considered, mainly dealing with: shape and dimensions of the part to be machined, tolerances, sequence of operations, machining strategies, cutting forces, number of set-ups, set-up times, volume of material to be removed, batch size, production rate, machine morphology, machine capacity, cost, etc. At the end, the solution can be characterized by its: simplicity, rigidity, accuracy, reliability, and economy [2]. Workpiece location in a fixture is significantly influenced by localized elastic deformation of the workpiece at the fixturing points. These deformations are caused by the clamping force(s) applied to the workpiece. For a relatively rigid workpiece, the localized elastic deformations cause it to undergo rigid body translations and rotations which alter its location with respect to the cutting tool. It is therefore important to minimize such effects through optimal design of the fixture layout [4].

S. K. Hargrove and A. Kusiak [5] recognize four general requirements of a fixture: (i) Accurate location of the workpiece, (ii) Total restraint of the workpiece during machining, (iii) Limited deformation of the workpiece, (iv) No machining interference. In addition, as set forth by R. T. Meyer and F. W. Liou [6], dynamic machining conditions occur when a workpart is subject to machining forces that move through the work part or along its surface. A viable fixture designed for a workpart experiencing dynamic machining must ensure: the workpart is restrained for all time, the clamping forces are not too large or small, deterministic positioning, accessibility, stability of the workpart in the fixture while under no external forces, and a positive clamping sequence.

Workpiece motion arising from localized elastic deformation at the workpiece/fixture contacts due to machining and clamping forces significantly affect the workpiece location accuracy and hence the machined part quality. The tangential friction force plays an important role in fixture configuration design as it can be utilized to reduce the number of fixture components, thereby the workpiece features accessibility to machining operations and providing a damping mechanism to dissipate input energy from machining forces out of the workpiece/fixture system. Contact problems with friction are generally complicated by the fact that the contact surface can experience slipping, sliding, rolling or tension release depending on the magnitude of the normal and tangential forces at the contact interface [8].

Considering all above mentioned facts, location & clamping is accomplished by using 3 V blocks and latch clamp. The important parts of fixture used here are V block, latch clamp, base plate, vertical plate, adapter plate, locator and rib [Fig. 4-7]. The fixture uses three V blocks to locate and a latch clamp to hold the component. The latch clamp consists of two M 6 bolts to directly clamp the workpiece. The chuck of CNC turning centre will be replaced with complete fixture set up using an adapter plate. The adapter plate holds the same dimensions of chuck plate. The locator locates the vertical plate in correct position with adapter plate. The base plate serves to hold the complete assembly of fixture. The ribs are clamped to base plate and provide the holding arrangement for latch clamp. The fixture rotates with 550 rpm while performing operations on CNC turning centre. The specification of spindle nose of CNC turning centre used in this work is $A_{2\text{-}8}$, which can carry a weight of 450 kg. The fixture is directly mounted on spindle nose.

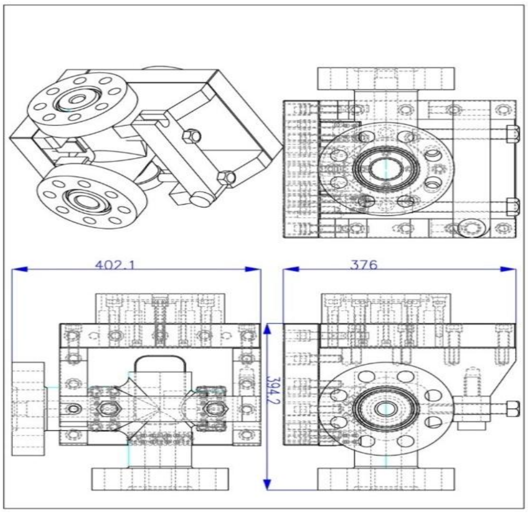

Figure 4. 2D drawing of fixture

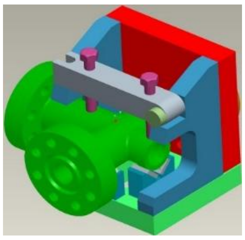

Figure 5. 3D view of fixture

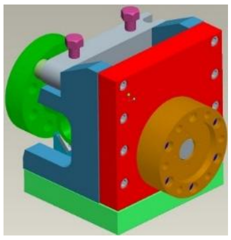

Figure 6. 3D rear view of fixture

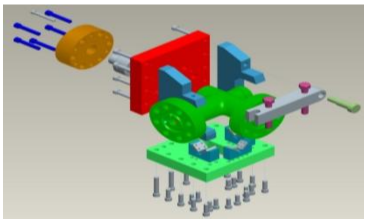

Figure 7. 3D exploded view of fixture

III. COMPUTER AIDED MASS BALANCING METHOD (CAMBM) FOR ROTARY FIXTURE

Methodology developed by most of the researchers mostly act as post-mortem tool, calculating and determining unbalanced mass after fixture is manufactured followed by unbalanced mass removal or counterweight addition. A tool that could predict unbalanced mass during fixture design stage is not yet developed. The present volume of this paper proposes the unique method of use of Creo Elements/Pro 5.0, which would enable prediction of unbalanced mass during design stage well before manufacturing. This approach would be highly useful in the shop floor, saving material cost, increasing the productivity and decreasing the human labor. In this work, fixture is balanced by adding counterweight equal in magnitude and opposite in direction as that of resultant unbalanced mass. The object of the work presented here is to develop the study and to provide the optimum conditions of design, manufacturing, static analysis with force & moment balancing of fixture. As the fixture is asymmetrical, it has to be mass balanced. The fixture rotates around one axis; hence it has to be balanced about other two perpendicular axis. Here x - axis is the axis of rotation. The results and outputs from Creo Elements/Pro 5.0 with solution of balancing are shown below.

3.1 IV Quadrant Computer Aided Mass Balancing Method

Step I: C. G., weight of fixture and offset distance of C. G. from axis of rotation are determined [Fig. 8]. The important results from the above output are as follows: weight of fixture with component, without balancing mass = 233.12 kg. C.G. is offset from axis of rotation in x – axis by -130.56 mm, in y – axis by -1.11 mm and in z – axis by 2.38 mm.

Step II: Now the fixture is cut in 4 quadrants about 2 axis, perpendicular to each other and perpendicular to axis of rotation below [Fig. 9].

Step III: The weight and C. G. of fixture in each quadrant are determined. [Fig. 10-13].

Step IV: The above outputs of weight of fixture and C. G. of each quadrant are summarized [Fig. 14, Table 1].

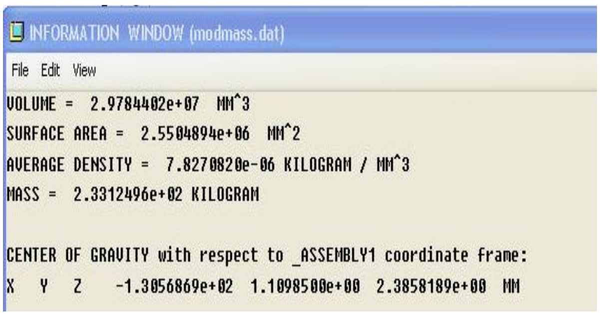

Figure 8. Mechanical Analysis of Fixture

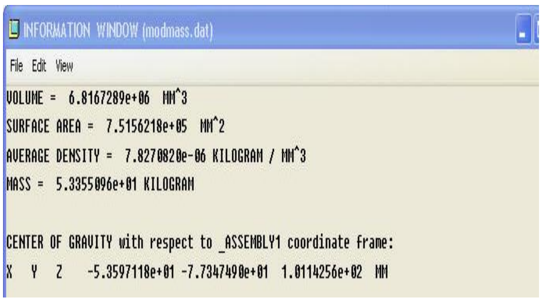

Figure 12. Weight and C. G. of fixture in Quadrant III

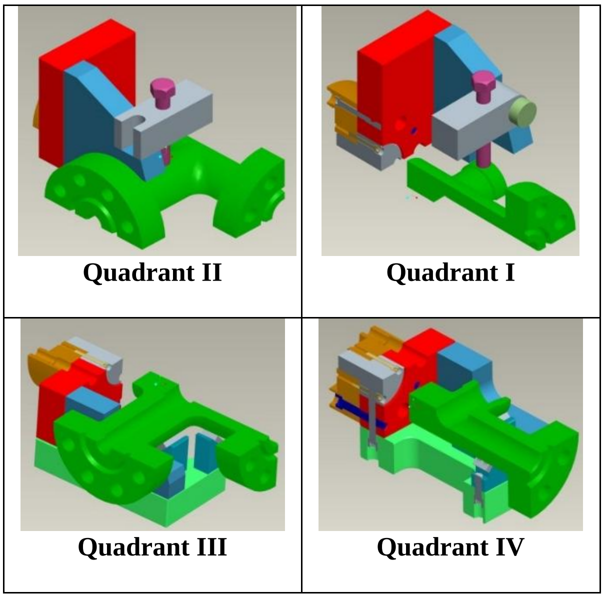

Figure 9. 3D view of fixture in 4 Quadrants

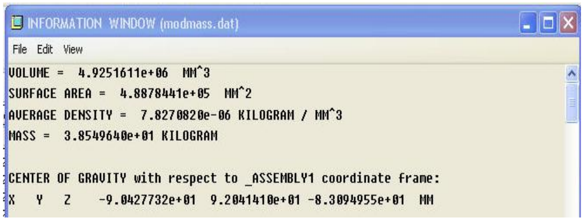

Figure 10. Weight and C. G. of fixture in Quadrant I

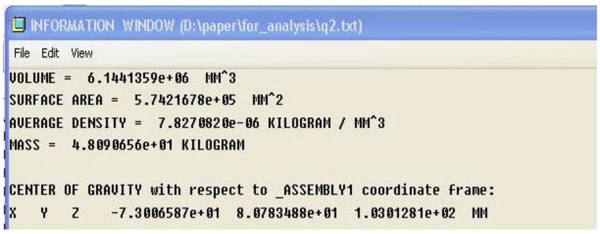

Figure 11. Weight and C. G. of fixture in Quadrant II

Figure 13. Weight and C. G. of fixture in Quadrant IV

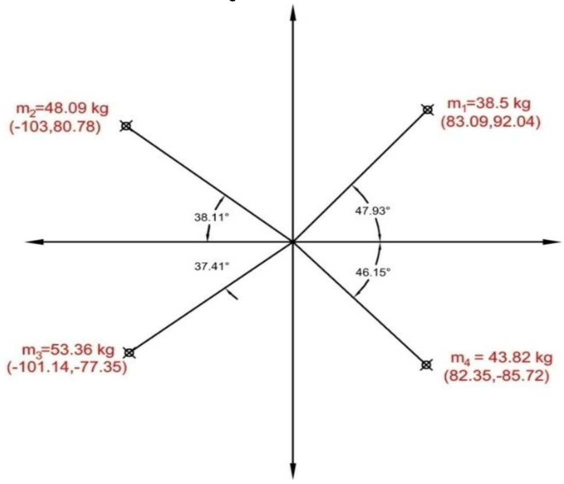

Figure 14. 2D drawing showing summary of weight and C. G. of fixture in all Quadrants

Table 1. Summary of C. G. of fixture in all Quadrants

Quadrant (i)	Co-ordinate of C. G. (mm)		$\tan \theta_i$	θ_i (Degree)
	x_i	y_i		
1	83.09	92.04	1.10	47.92
2	-103	80.78	-0.78	38.11
3	101.14	77.35	0.76	37.41
4	82.35	85.71	-1.04	46.14

Step V: According to principles of mechanics, $\Sigma F = 0$ and $\Sigma M = 0$ for mass balancing. The sum of unbalanced mass in horizontal direction ΣF_H and in vertical direction ΣF_V are calculated [Table 2].
Step VI: Resultant unbalanced mass (R) and its line of action in terms of angle (α) with x-axis are calculated using parallelogram law of forces [Table 3].
Step VII: Sum of moment of inertia about x – axis ($\Sigma m_i x_i^2$) and that about y – axis ($\Sigma m_i y_i^2$) are calculated [Table 4].
Step VIII: Resultant moment is calculated using principle of perpendicular axis theorem of moment of inertia [Table 5].

Table 2. Calculation of resultant mass in horizontal direction (ΣF_H) and in vertical direction(ΣF_V)

Quadrant (i)	m_i (kg)	$F_H = x_i = m_i \cos\theta_i$ (kg)	$F_V = y_i = m_i \sin\theta_i$ (kg)
1	38.5	25.79868396	28.57757698
2	48.09	-37.8405504	29.67727827
3	53.36	-42.38538755	-32.41555988
4	43.82	30.35986498	-31.59859171
	Σ	**-24.06738901**	**-5.75929635**

Table 3. Calculation of Resultant Force, R

ΣF_H^2	579.2392137 kg^2
ΣF_V^2	33.16949445 kg^2
$\Sigma F_H^2 + \Sigma F_V^2$	612.4087082 kg^2
Resultant, $R = \sqrt{(\Sigma F_H^2 + \Sigma F_V^2)}$	24.7468929 kg
tan α	0.23929876
α	13.45773737°

Table 4. Calculation of sum of moment of Inertia about X – direction ($\Sigma m_i x_i^2$) and that of about Y – direction ($\Sigma m_i y_i^2$)

Quadrant (i)	m_i (kg)	$m_i x_i^2$ ($kg\ mm^2$)	$m_i y_i^2$ ($kg\ mm^2$)
1	38.5	265802.0019	326147.4216
2	48.09	510186.81	313806.89
3	53.36	545835.4267	319254.0806
4	43.82	297166.316	321910.6637
	Σ	**1618990.554**	**1281119.056**

Table 5. Calculation of Resultant Moment, M

$I_{xx} = \Sigma m_i x_i^2$	= 1618990.554 $kg\ mm^2$
$I_{yy} = \Sigma m_i y_i^2$	= 1281119.056 $kg\ mm^2$
$I_{zz} = I_{xx} + I_{yy}$ $\therefore M = \Sigma m_i x_i^2 + \Sigma m_i y_i^2$	= 2900109.61 $kg\ mm^2$

Step IX: Having M, R and α, the location of C. G. (r_{cm}) of R is determined.

$$M = R\, r_{cm}^2$$

$$\therefore r_{cm}^2 = M / R$$

$$\therefore r_{cm} = 342.33 \text{ mm}$$

Thus the unbalanced mass is found to be 24.75 kg and its C. G. is situated at an angle of 13.45° with x-axis at a distance of 342.33 mm in quadrant III. Hence the fixture can be balanced by placing the counterweight equal in magnitude and opposite in direction as that of unbalanced mass.

3.2 VIII Quadrant Computer Aided Mass Balancing Method

Step I: This step is same as in IV Quadrant Computer Aided Mass Balancing Method.

Step II: Now the fixture is cut in 8 quadrants around 4 axis at angle of 45^0 to each other and perpendicular to axis of rotation.

Step III: The weight and C. G. of fixture in each quadrant are determined. [Fig. 15-22].

Step IV: The above outputs of weight of fixture and C. G. of each quadrant are summarized [Table 6].

Step V: According to principles of mechanics, ΣF = 0 and ΣM = 0 for mass balancing. The sum of unbalanced mass in horizontal direction ΣF_H and in vertical direction ΣF_V are calculated [Table 7].

Step VI: Sum of moment of inertia about x – axis ($\Sigma m_i x_i^2$) and that about y – axis ($\Sigma m_i y_i^2$) are calculated [Table 8].

Step VII: Resultant unbalanced mass (R) and its line of action in terms of angle (α) with x-axis are calculated using parallelogram law of forces [Table 9].

Step VIII: Resultant moment is calculated using principle of perpendicular axis theorem of moment of inertia [Table 10].

Step IX: Having M, R and α, the location of C. G. (r_{cm}) of R is determined.

$$M = R\, r_{cm}^2$$

$$\therefore r_{cm}^2 = M / R$$

$$\therefore r_{cm} = 159.11 \text{mm}$$

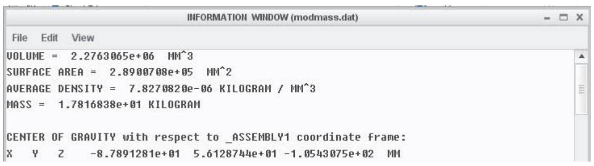

Figure 15. Weight and C. G. of fixture in Quadrant I

Figure 22. Weight and C. G. of fixture in Quadrant VIII

Table 6. Summary of C. G. of fixture in all

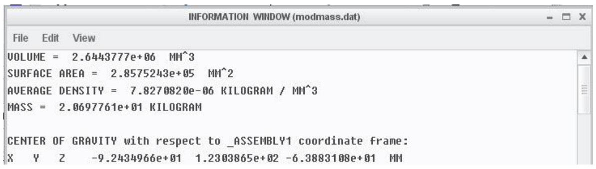

Figure 16. Weight and C. G. of fixture in Quadrant II

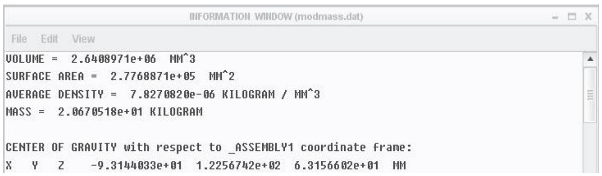

Figure 17. Weight and C. G. of fixture in Quadrant III

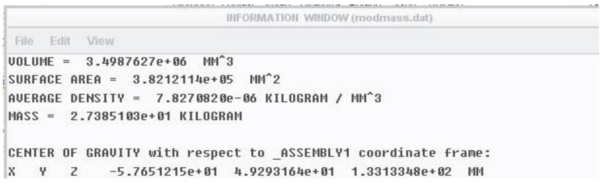

Figure 18. Weight and C. G. of fixture in Quadrant IV

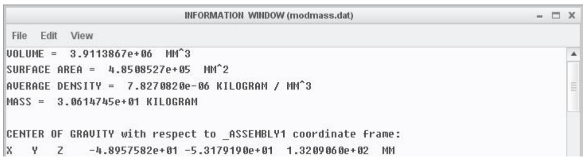

Figure 19. Weight and C. G. of fixture in Quadrant V

Figure 20. Weight and C. G. of fixture in Quadrant VI

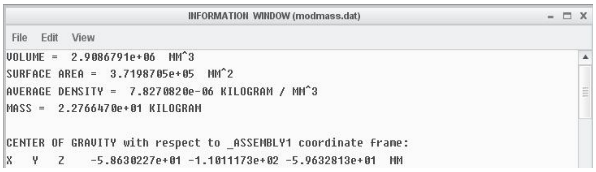

Figure 21. Weight and C. G. of fixture in Quadrant VII

Quadrants

Quadrant (i)	**Co-ordinate of C.G. (mm)**		**tan θ_i**	**θ_i (Degree)**
	x_i	**y_i**		
1	105.43	56.13	0.53	28.03
2	6.883	123.04	17.87	86.80
3	-63.16	122.57	-1.94	62.73
4	-133.13	49.29	-0.37	20.32
5	-132.09	-53.18	0.40	21.93
6	-59.39	-110.14	1.85	61.66
7	59.63	-110.11	-1.84	61.56
8	107.13	-59.26	-0.55	28.95

Table 7. Calculation of resultant mass in horizontal direction (ΣF_H) and in vertical direction(ΣF_V)

Quadrant (i)	**mass m_i (kg)**	**$F_H=x_i=m_i \cos\theta_i$ (kg)**	**$F_V=y_i=m_i \sin\theta_i$ (kg)**
1	17.82	15.72967885	8.374341968
2	20.70	1.156174297	20.6676864
3	20.67	-9.468080697	18.37401284
4	27.38	-25.67665437	9.506514638
5	30.61	-28.39510038	-11.43198908
6	22.60	-10.72639375	-19.89232207
7	22.77	10.84315128	-20.02246164
8	20.91	18.2972081	-10.12127837
	Σ	**-18.25888192**	**56.92255584**

Table 8. Calculation of sum of moment of Inertia about X – direction ($\Sigma m_i x_i^2$) and that of about Y – direction ($\Sigma m_i y_i^2$)

Quadrant (i)	**m_i (kg)**	**$m_i x_i^2$ (kg mm^2)**	**$m_i y_i^2$ (kg mm^2)**
1	17.82	198077.9409	56143.28036
2	20.7	980.6767623	313374.0211
3	20.67	82456.46635	310533.7793
4	27.38	485272.0831	66519.82226

5	30.61	534076.1815	86568.52056
6	22.6	79714.08946	274156.523
7	22.77	80964.12921	276068.3095
8	20.91	239980.6596	73430.64232
	Σ	**766787.1672**	**746570.903**

Table 9. Calculation of Resultant Force, R

ΣFH2	333.386769 kg2
ΣFV2	3240.177364 kg2
ΣFH2 + ΣFV2	3573.564133 kg2
Resultant, R = √ (ΣFH2 + ΣFV2)	59.77929518 kg
tan α	-3.11752692
(degree)	72.21546938

Table 10. Calculation of Resultant Moment, M

Ixx = Σmixi2	A766787.1672 kg mm2
Iyy = Σmiyi2	746570.903 kg mm2
Izz = Ixx + Iyy ∴ M = Σmixi2+ miyi2	1513358.07 kg mm2

Thus the unbalanced mass is found to be 59.78 kg and its C. G. is situated at an angle of 72.22^{o} with x-axis at a distance of 159.11 mm in quadrant III. Hence the fixture can be balanced by placing the counterweight equal in magnitude and opposite in direction as that of unbalanced mass.

3.3 VIII Diamond Quadrant Computer Aided Mass Balancing Method

Step I: This step is same as in IV Quadrant Computer Aided Mass Balancing Method.

Step II: Now the fixture is cut in VIII quadrants in diamond cutting method and perpendicular to axis of rotation [Fig. 23].

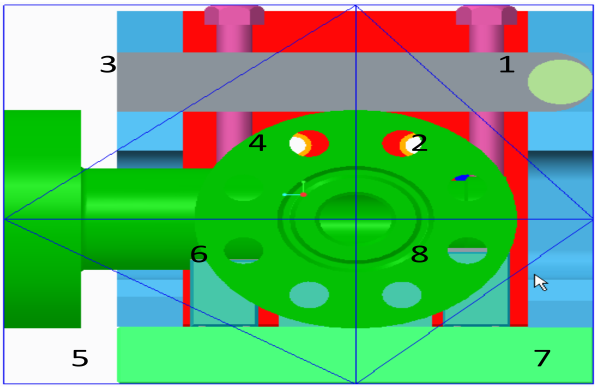

Figure 23. 3D view of fixture in VIII Quadrants

Step III: The weight and C. G. of fixture in each quadrant are determined. [Fig. 24-31].

Step IV: The above outputs of weight of fixture and C. G. of each quadrant are summarized [Table 11].

Step V: According to principles of mechanics, ΣF = 0 and ΣM = 0 for mass balancing. The sum of unbalanced mass in horizontal direction ΣF_H and in vertical direction ΣF_V are calculated [Table12].

Step VI: Sum of moment of inertia about x – axis ($\Sigma m_i x_i^2$) and that about y – axis ($\Sigma m_i y_i^2$) are calculated [Table 13].

Step VII: Resultant unbalanced mass (R) and its line of action in terms of angle (α) with x-axis are calculated using parallelogram law of forces [Table 14].

Step VIII: Resultant moment is calculated using principle of perpendicular axis theorem of moment of inertia [Table 15].

Step IX: Having M, R and α, the location of C. G. (r_{cm}) of R is determined.

$$M = R\, r_{cm}^2$$

$$\therefore r_{cm}^2 = M / R$$

$$\therefore r_{cm} = 164.79 mm$$

Thus the unbalanced mass is found to be 59.51 kg and its C. G. is situated at an angle of 77.82° with x-axis at a distance of 164.79 mm in quadrant II. Hence the fixture can be balanced by placing the counterweight equal in magnitude and opposite in direction as that of unbalanced mass.

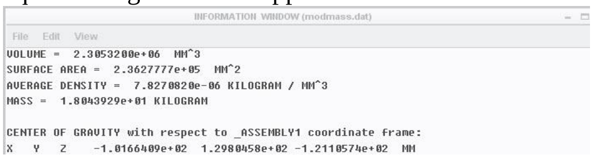

Figure 24. Weight and C. G. of fixture in Quadrant I

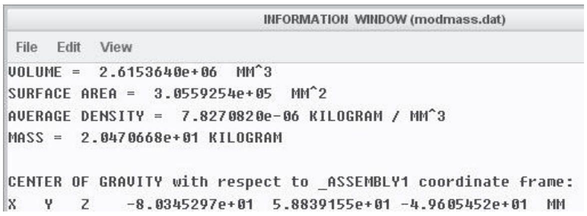

Figure 25. Weight and C. G. of fixture in Quadrant II

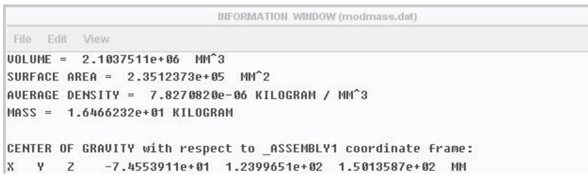

Figure 26. Weight and C. G. of fixture in Quadrant III

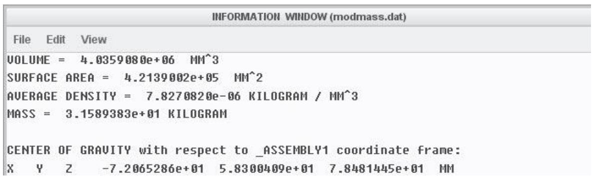

Figure 27. Weight and C. G. of fixture in Quadrant IV

Figure 28. Weight and C. G. of fixture in Quadrant V

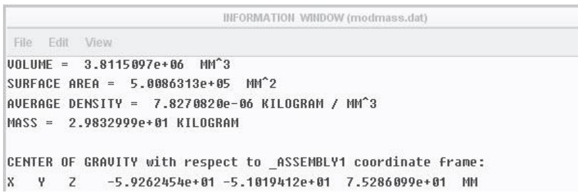

Figure 29. Weight and C. G. of fixture in Quadrant VI

Figure 31. Weight and C. G. of fixture in Quadrant VIII

Table 11. Summary of C. G. of fixture in all Quadrants

Quadrant (i)	Co-ordinate of C.G. (mm)		tan θ_i	θ_i (Degree)
	x_i	y_i		
1	121.1	129.8	1.071	46.9859
2	49.6	58.84	1.186	49.8703
3	-150.13	124	-0.82	39.5550
4	-78.48	58.33	-0.74	36.62145
5	-134.3	-111	0.826	39.57399
6	-75.29	-51.62	0.685	34.43514
7	50	-50.62	-1.01	45.35304
8	109.45	-115.15	-1.05	46.45376

Table 12. Calculation of resultant mass in horizontal direction (ΣF_H) and in vertical direction(ΣF_V)

Quadrant (i)	mass m_i (kg)	$F_H = x_i = m_i Cos \theta_i$ (kg)	$F_V = y_i = m_i Sin \theta_i$ (kg)
1	18.04	12.30648648	13.1906023
2	20.47	13.19332048	15.6511084
3	16.47	-12.6985887	10.4884100
4	31.59	-25.35394953	18.8442389
5	23.38	-18.02136111	-14.894795
6	29.83	-24.60279378	-16.868059
7	19.9	13.98445421	-14.157861
8	23.79	16.38987502	-17.243436
	Σ	**-12.55273126**	**58.1743598**

Table 13. Calculation of sum of moment of Inertia

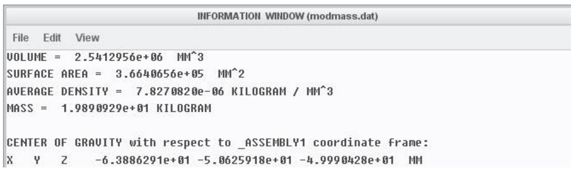

Figure 30. Weight and C. G. of fixture in Quadrant VII

about X – direction ($\Sigma m_i x_i^2$) and that of about Y – direction ($\Sigma m_i y_i^2$)

Quadrant (i)	**m_i (kg)**	**$m_i x_i^2$ (kg mm^2)**	**$m_i y_i^2$ (kg mm^2)**
1	18.04	264560.3884	303938.641
2	20.47	50359.4752	70870.1204
3	16.47	371217.6083	253242.72
4	31.59	194566.2975	107481.465
5	23.38	421693.1362	288064.98
6	29.83	169093.8637	79485.7458
7	19.9	49750	50991.4495
8	23.79	284987.6065	315444.040
	Σ	**880703.7695**	**735532.947**

Table 14. Calculation of Resultant Force, R

ΣF_H^2	157.5710622 kg^2
ΣF_V^2	3384.256138 kg^2
$\Sigma F_H^2 + \Sigma F_V^2$	3541.8272 kg^2
Resultant, $R = \sqrt{(\Sigma F_H^2 + \Sigma F_V^2)}$	59.51325231 kg
tan α	-4.63439857
α (degree)	77.823534840

Table 15. Calculation of Resultant Moment, M

$I_{xx} = \Sigma m_i x_i^2$	880703.7695 kg mm^2
$I_{yy} = \Sigma m_i y_i^2$	735532.9474 kg mm^2
$I_{zz} = I_{xx} + I_{yy}$ ∴ $M = \Sigma m_i x_i^2 + m_i y_i^2$	1616236.717 kg mm^2

3.4 Comparison of Results obtained of two methods used for Mass Balancing

	Mass Balancing Method		
Parameters	**IV Quadrant Method**	**VIII Quadrant Method**	**VIII Diamond Quadrant Method**
Unbalanced Mass (kg)	24.75	59.78	59.51
Angle at which C.G. of unbalanced mass is situated	13.45^0	72.22^0	77.82^0
Distance at which C.G. of unbalanced mass is situated	342.33 mm	159.11 mm	164.79 mm
Quadrant in which C.G. of unbalanced mass is situated	III	II	II
Mass of component (kg)	46.5	46.5	46.5
Mass of fixture including mass of component, excluding unbalanced mass (kg)	183.46	183.46	183.46
Total mass of fixture including mass of component and unbalanced mass (kg)	208.21	243.24	242.97
Actual mass of fixture including mass of component and unbalanced mass (kg)	233.12	233.12	233.12
Absolute Error	24.91	10.12	9.85
Relative Error	0.10685	0.04341	0.04225
Percentage Error	10.685	4.341	4.225

The above comparison shows that VIII Diamond Quadrant Computer Aided Mass Balancing Method gives more accurate results compared with experimental results. Moreover, results obtained from VIII Quadrant and VIII Diamond Quadrant Computer Aided Mass Balancing Method are almost same. Percentage error in these two methods is reduced by almost 6 % in comparison to IV Quadrant Computer Aided Mass Balancing Method.

IV. ANALYTICAL ANALYSIS

As main operation to be performed on component is outside diameter turning and maximum cutting force acts for this operation; calculation is made for the same.

4.1 Nomenclature

a_s = Average chip thickness
D = Diameter of workpiece
HB = Brinell Hardness
K_h = Correction factor for flank wear
K_γ = Correction factor for rake angle
n = revolutions per minute
N = Power at the spindle
N_{el} = Power of the motor
P_z = Tangential cutting force
Q = metal removal rate
s = Feed per revolution
S_m = feed per minute
t = Depth of cut
T_s = Torque at the spindle
U = Unit power
v = Cutting speed
x = Approach angle

4.2 Analytical Calculation

The cutting conditions are as under:
D = 223.4 mm,
n = 550 rpm,
s = 0.3 mm / rev,
t = 0.75 mm,
$x = 45^0$,
$U = 0.03\ kW/cm^3/min$,

$$\text{Cutting speed, } v = \pi Dn / 1000 \quad (1)$$

$$v = 386 \text{ m/min}$$

$$\text{Feed per minute, } S_m = sn \quad (2)$$

$$S_m = 165 \text{ mm / min}$$

$$\text{Metal removal rate, } Q = stv \quad (3)$$

$$Q = 86.85 \text{ cm}^3/\text{min}$$

$$\text{Average chip thickness, } a_s = s \sin x \quad (4)$$

$$a_s = 0.212 \text{ mm}$$

For, component material of mild steel, HB = 300, a_s = 0.212 mm and assuming flank wear of 0.2 mm, Correction factor for flank wear, K_h = 1.09
For Rake angle = 10^o, Correction factor for rake angle K_γ = 1

$$\text{Power at the spindle, } N = U \text{ x kh x k}\gamma \text{ x } Q \quad (5)$$

$$N = 2.84 \text{ kW}$$

Assuming, Efficiency of transmission, E = 85 %

$$\text{Power of the motor, } N_{el} = N / E \quad (6)$$

$$N_{el} = 3.34 \text{ kW}$$

$$\text{Tangential cutting force, } P_z = 6120Ng / v \quad (7)$$

$$P_z = 519.49 \text{ N}$$

$$\text{Torque at the spindle, } T_s = 975 \text{ x } N / n \quad (8)$$

$$T_s = 58.07 \text{ N.m}$$

As cutting force is only 519.49 N, two M 6 bolts with clamping force of 2.5 kN each is used to clamp the workpiece.

V. CONCLUSION

An integrated approach of design and mass balancing of rotary fixture has been adopted in this work.

This approach is of crucial importance in real manufacturing environment. Actually HMC is the best solution for performing the required operations on part used in this work, but a designer cannot ask industry to replace already existing set up of CNC turning centre with HMC as HMC costs around 12.5 million rupees whereas CNC turning centre costs only about 2.5 million rupees. Here the research work of this paper is proved, 10 million rupees are straight away saved in machine installation cost. In HMC, a tool rotates and component remains stationary, vice versa for CNC turning centre. A designed fixture has the important novel characteristic of performing all operations in a single set up with component rotating and tool stationary, satisfying the essential requirement of CNC turning centre.

A simplified, analytical method of use of Creo Elements/Pro 5.0 is proposed to solve the balancing problem. The approach of application of Creo Elements/Pro 5.0 to mass balance the fixture is very useful as it opens the door not only to symmetrical part problems but also to a more general class of problem and difficult tasks such as asymmetrical fixture as is the case in this work. The application of Creo Elements/Pro 5.0 and principles of mechanics used in this work to overcome balancing problem is universal i.e. applicable for any part. The findings of unbalanced mass and its location of C. G. are remarkably same as with experimental results on dynamic balancing machine. This approach of solving the balancing problem is expected to have more flexibility in its application, since it is not sensitive to dynamic conditions.

The present research work also proposes Computer Aided Mass Balancing Method (CAMBM) which ease fixture designer from tedious and time consuming work of finding offset distance and C.G. of irregular shape parts and also solving mass balancing problem. Three alternate methods of Computer Aided Mass Balancing are presented and VIII Quadrant Computer Aided Mass Balancing Method is found more accurate with the result of decrease in percentage error by almost 6 %.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the support of Mr. Sudhir Thakar and Mr. Pradip Thanki, Trend Enterprise, Rajkot, Gujarat, India for this research work. The authors also acknowledge the support of Mr. Chetan M. Patel for his input to this research work.

REFERENCES

1) Koji Teramoto; Masahiko Anasoto; Kazuaki Iwata. Coordinative Generation of Machining and Fixturing Plans by a Modularized Problem Solver. CIRP Annuals, Manufacturing Technology, 1998, 47, pp. 437–440.
2) Hunter, R.; Rios, J.; Perez J. M.; Vizan, A. A functional approach for the formalization of the fixture design process. International Journal of machine tools and manufacture, 2006, 46, pp. 683–697.
3) Hunter, R.; Vizan, A.; Perez, J.; Rios, J. Knowledge model as an integral way to reuse the knowledge for fixture design process. Journal of material processing technology, 2005, 164 – 165, pp.1510–1518.
4) Bo Li; Shreyes N. Melkote. Improved workpiece location accuracy through fixture layout optimization. International Journal of machine tools and manufacture, 1999, 39, pp. 871–883.
5) Hargrove, S. K.; Kusiak, A. Computer-aided fixture design: a review. International Journal of Production Research, 1994, 32, pp. 733–753.
6) Meyer, R. T.; Liou, F. W. Fixture analysis under dynamic machining. International Journal of Production Research, 1997, 35, pp. 1471–1489.
7) Arakelian, V.; Dahan, M. Dynamic balancing of mechanisms. Mechanics research communication, 2000, 27, pp. 1-6.
8) Ibrahim M. Deiab; Mohamed A. Elbestawi. Experimental determination of the friction coefficient on the workpiece-fixture contact surface in workholding applications. International Journal of Machine Tools & Manufacture, 2005, 45, pp. 705-712.