Design & Development Of Rotary Fixture For CNC With An Approach Of Developing Pre-Mortem Tool For Mass Balancing

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Abstract

Various areas related to fixture are already been described by renowned authors, still there is need to apply these research works to an industrial application. This paper presents design of rotary fixture for real industrial component - Flow TEE body of petroleum refinery. The operations to be performed are front facing, outside diameter turning, grooving, boring and back facing. Actually HMC is the best solution for performing these operations, but HMC costs about 12.5 million rupees whereas CNC turning centre costs about 2.5 million rupees. As these operations can now be performed on CNC turning centre using the designed fixture; 10 million rupees are saved in installation cost. Methodology for mass balance of rotary fixture 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 before manufacturing with three alternate methods for mass balancing.

1. 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 turning centre to function as HMC.

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.

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.

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 mass balancing of 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. 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 turning centre to function as HMC.

2. Design & Development of Rotary Fixture for CNC turning centre to function as HMC

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]. 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.

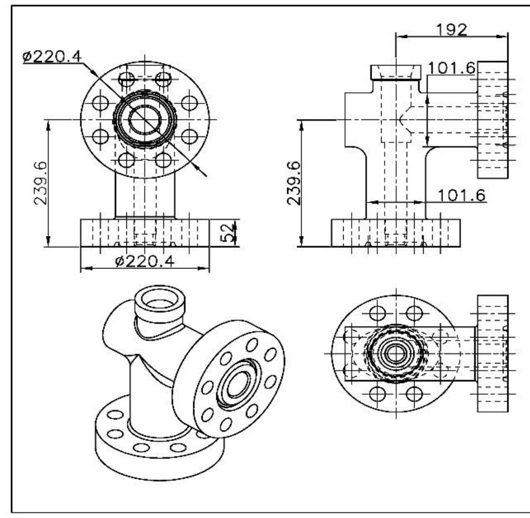


Figure 1. Finished Component Drawing

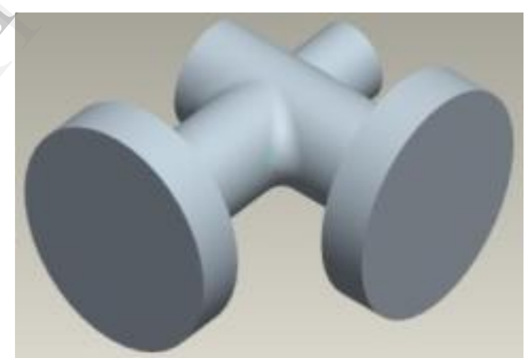


Figure 2. 3D view of raw material of component

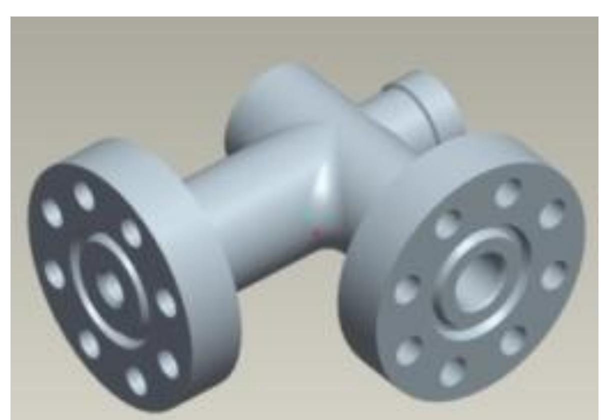


Figure 3. 3D view of finished part

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]. 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. 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 A2-8, which can carry a weight of 450 kg. The fixture is directly mounted on spindle nose.

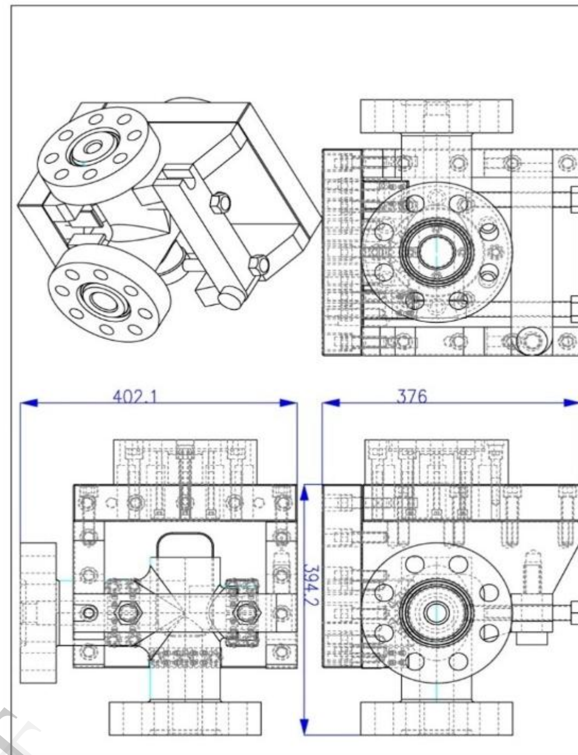


Figure 4. 2D drawing of fixture

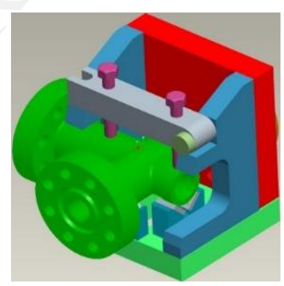


Figure 5. 3D view of fixture

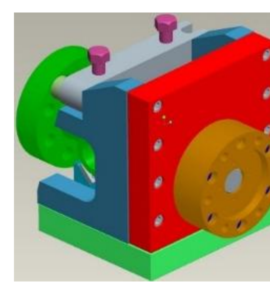


Figure 6. 3D rear view of fixture

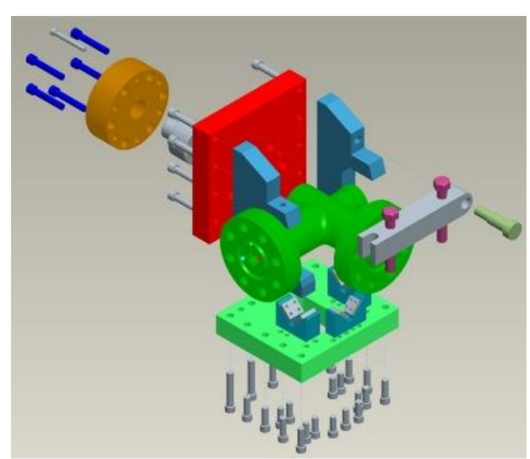


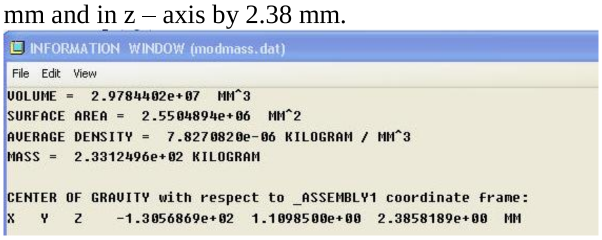
Figure 7. 3D exploded view of fixture

3. Computer Aided Mass Balancing Method (CAMBM)

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 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.


INFORMATION WINDOW (modmass.dat)
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VOLUME = 2.9784402e+07 MM^3
SURFACE AREA = 2.5504894e+06 MM^2
AVERAGE DENSITY = 7.8270820e-06 KILOGRAM / MM^3
MASS = 2.3312496e+02 KILOGRAM

CENTER OF GRAVITY with respect to _ASSEMBLY1 coordinate frame:
X Y Z -1.3056869e+02 1.1098500e+00 2.3858189e+00 MM

Figure 8. Mechanical Analysis of Fixture

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 outputs of weight of fixture and C. G. of each quadrant are summarized [Fig. 14, Table 1].

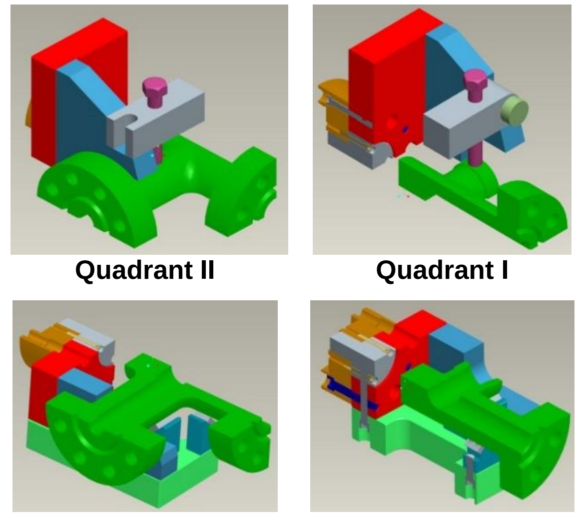
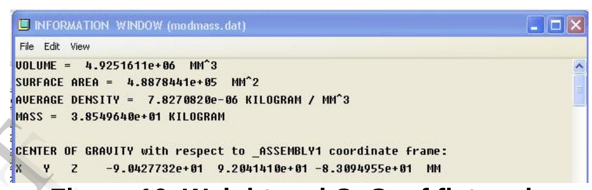


Figure 9. 3D view of fixture in 4 Quadrants


INFORMATION WINDOW (modmass.dat)
File Edit View
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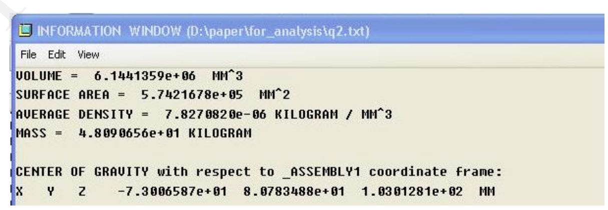
SURFACE AREA = 4.8878441e+05 MM^2
AVERAGE DENSITY = 7.8270820e-06 KILOGRAM / MM^3
MASS = 3.8549640e+01 KILOGRAM

CENTER OF GRAVITY with respect to _ASSEMBLY1 coordinate frame:
X Y Z -9.0427732e+01 9.2041410e+01 -8.3094955e+01 MM

Figure 10. Weight and C. G. of fixture in Quadrant I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File Edit View
VOLUME = 6.1441359e+06 MM^3
SURFACE AREA = 5.7421678e+05 MM^2
AVERAGE DENSITY = 7.8270820e-06 KILOGRAM / MM^3
MASS = 4.8090656e+01 KILOGRAM

CENTER OF GRAVITY with respect to _ASSEMBLY1 coordinate frame:
X Y Z -7.3006587e+01 8.0783488e+01 1.0301281e+02 MM

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


INFORMATION WINDOW (modmass.dat)
File Edit View
VOLUME = 6.8167289e+06 MM^3
SURFACE AREA = 7.5156218e+05 MM^2
AVERAGE DENSITY = 7.8270820e-06 KILOGRAM / MM^3
MASS = 5.3355096e+01 KILOGRAM

CENTER OF GRAVITY with respect to _ASSEMBLY1 coordinate frame:
X Y Z -5.3597118e+01 -7.7347490e+01 1.0114256e+02 MM

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


INFORMATION WINDOW (D:\paper\for_analysis\q4.txt)
File Edit View
VOLUME = 5.5983705e+06 MM^3
SURFACE AREA = 6.5260301e+05 MM^2
AVERAGE DENSITY = 7.8270820e-06 KILOGRAM / MM^3
MASS = 4.3818905e+01 KILOGRAM

CENTER OF GRAVITY with respect to _ASSEMBLY1 coordinate frame:
X Y Z -6.5167750e+01 -8.5713038e+01 -8.2345163e+01 MM

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

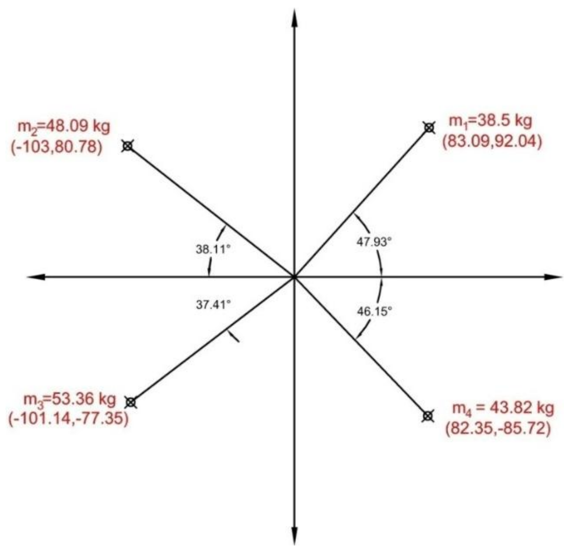


Figure 14. 2D drawing showing summary of weight and C. G. of fixture in all Quadrants

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, 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 2].

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	38.55	25.79868396	28.5775769
2	48.09	-37.8405504	29.6772782
3	53.36	-42.38538755	-32.415559
4	43.82	30.35986498	-31.598591
	Σ	**-24.06738901**	**-5.7592963**

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].

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
$\tan\alpha$	0.23929876
α	13.45773737°

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].

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	326147.421
2	48.09	510186.81	313806.89
3	53.36	545835.4267	319254.080
4	43.82	297166.316	321910.663
	Σ	**1618990.554**	**1281119.05**

Step VIII: Resultant moment is calculated using principle of perpendicular axis theorem of moment of inertia [Table 5].

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

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

$$M = R\, rcm^2$$
$$r_{cm}^2 = M / R$$
$$r_{cm} = 342.33 \text{ mm}$$

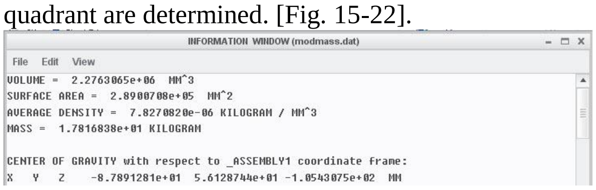
Thus the unbalanced mass is found to be 24.75 kg and its C. G. is situated at an angle of 13.45° with x-axis at a distance of 342.33 mm in quadrant III. Hence the fixture can be balanced by placing the counterweight equal in magnitude and opposite in direction as that of unbalanced mass.

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 VIII quadrants about 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].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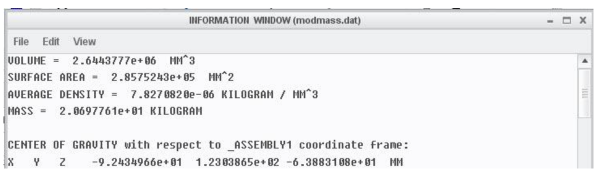
AVERAGE DENSITY = 7.8270820e-06 KILOGRAM / MM^3
MASS = 1.7816838e+01 KILOGRAM

CENTER OF GRAVITY with respect to _ASSEMBLY1 coordinate frame:
X Y Z -8.7891281e+01 5.6128744e+01 -1.0543075e+02 MM

Figure 15. Weight and C. G. of fixture in Quadrant I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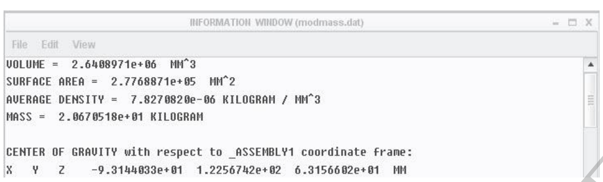
SURFACE AREA = 2.8575243e+05 MM^2
AVERAGE DENSITY = 7.8270820e-06 KILOGRAM / MM^3
MASS = 2.0697761e+01 KILOGRAM

CENTER OF GRAVITY with respect to _ASSEMBLY1 coordinate frame:
X Y Z -9.2434966e+01 1.2303865e+02 -6.3883108e+01 MM

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


INFORMATION WINDOW (modmass.dat)
File Edit View
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SURFACE AREA = 2.7768871e+05 MM^2
AVERAGE DENSITY = 7.8270820e-06 KILOGRAM / MM^3
MASS = 2.0670518e+01 KILOGRAM

CENTER OF GRAVITY with respect to _ASSEMBLY1 coordinate frame:
X Y Z -9.3144033e+01 1.2256742e+02 6.3156602e+01 MM

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


INFORMATION WINDOW (modmass.dat)
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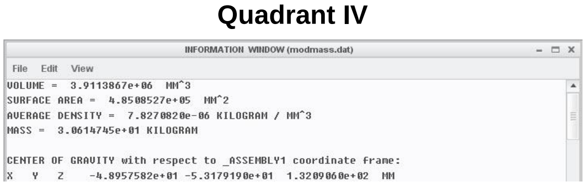
VOLUME = 3.4987627e+06 MM^3
SURFACE AREA = 3.8212114e+05 MM^2
AVERAGE DENSITY = 7.8270820e-06 KILOGRAM / MM^3
MASS = 2.7385103e+01 KILOGRAM

CENTER OF GRAVITY with respect to _ASSEMBLY1 coordinate frame:
X Y Z -5.7651215e+01 4.9293164e+01 1.3313348e+02 MM

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


INFORMATION WINDOW (modmass.dat)
File Edit View
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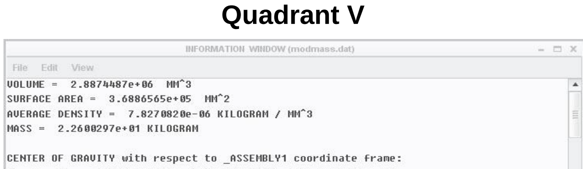
SURFACE AREA = 4.8508527e+05 MM^2
AVERAGE DENSITY = 7.8270820e-06 KILOGRAM / MM^3
MASS = 3.0614745e+01 KILOGRAM

CENTER OF GRAVITY with respect to _ASSEMBLY1 coordinate frame:
X Y Z -4.8957582e+01 -5.3179190e+01 1.3209060e+02 MM

Figure 19. Weight and C. G. of fixture in Quadrant V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File Edit View
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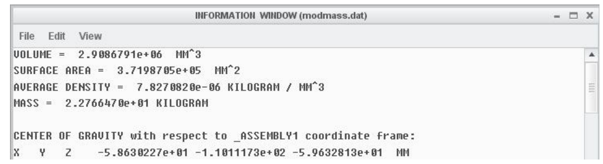
SURFACE AREA = 3.6886565e+05 MM^2
AVERAGE DENSITY = 7.8270820e-06 KILOGRAM / MM^3
MASS = 2.2600297e+01 KILOGRAM

CENTER OF GRAVITY with respect to _ASSEMBLY1 coordinate frame:
X Y Z -5.9091511e+01 -1.1014073e+02 5.9392926e+01 MM

Figure 20. Weight and C. G. of fixture in Quadrant VI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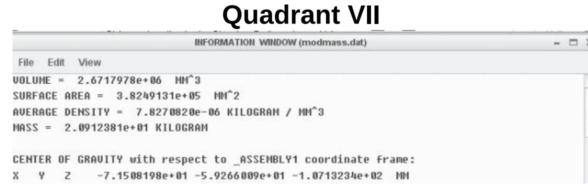
SURFACE AREA = 3.7198705e+05 MM^2
AVERAGE DENSITY = 7.8270820e-06 KILOGRAM / MM^3
MASS = 2.2766470e+01 KILOGRAM

CENTER OF GRAVITY with respect to _ASSEMBLY1 coordinate frame:
X Y Z -5.8630227e+01 -1.1011173e+02 -5.9632813e+01 MM

Figure 21. Weight and C. G. of fixture in Quadrant VII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SURFACE AREA = 3.8249131e+05 MM^2
AVERAGE DENSITY = 7.8270820e-06 KILOGRAM / MM^3
MASS = 2.0912381e+01 KILOGRAM

CENTER OF GRAVITY with respect to _ASSEMBLY1 coordinate frame:
X Y Z -7.1508198e+01 -5.9266009e+01 -1.0713234e+02 MM

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

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

Table 6. 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	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

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].

Table 7. Calculation of resultant mass in horizontal (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	17.82	15.72967885	8.37434196
2	20.70	1.156174297	20.6676864
3	20.67	-9.468080697	18.3740128
4	27.38	-25.67665437	9.50651463
5	30.61	-28.39510038	-11.431989
6	22.60	-10.72639375	-19.892322
7	22.77	10.84315128	-20.022461
8	20.91	18.2972081	-10.121278
	Σ	**-18.25888192**	**56.9225558**

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].

Table 8. Sum of moment of Inertia about X ($\Sigma m_i x_i^2$) and 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	56143.2803
2	20.7	980.6767623	313374.021
3	20.67	82456.46635	310533.779
4	27.38	485272.0831	66519.8222
5	30.61	534076.1815	86568.5205
6	22.6	79714.08946	274156.523
7	22.77	80964.12921	276068.309
8	20.91	239980.6596	73430.6423
	Σ	**766787.1672**	**746570.903**

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].

Table 9. Calculation of Resultant Force, R

ΣF_H^2	333.386769 kg^2
ΣF_V^2	3240.177364 kg^2
$\Sigma F_H^2 + \Sigma F_V^2$	3573.564133 kg^2
Resultant, $R = \sqrt{(\Sigma F_H^2 + \Sigma F_V^2)}$	59.77929518 kg
tan α	-3.11752692
α	72.21546938^0

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

Table 10. Calculation of Resultant Moment, M

$I_{xx} = \Sigma m_i x_i^2$	766787.1672 kg mm^2
$I_{yy} = \Sigma m_i y_i^2$	746570.903 kg mm^2
$I_{zz} = I_{xx} + I_{yy}$ ∴ $M = \Sigma m_i x_i^2 + \Sigma m_i y_i^2$	1513358.07 kg mm^2

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

$$M = R\, r_{cm}^2$$
$$r_{cm}^2 = M / R$$
$$r_{cm} = 159.11\text{mm}$$

Thus the unbalanced mass is found to be 59.78 kg and its C. G. is situated at an angle of 72.22° with x-axis at a distance of 159.11 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.

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].

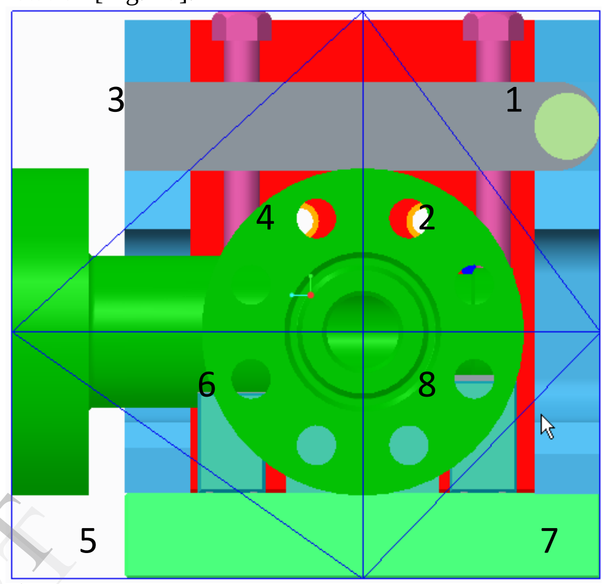

Figure 23. 3D view of fixture in VIII Quadrants

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

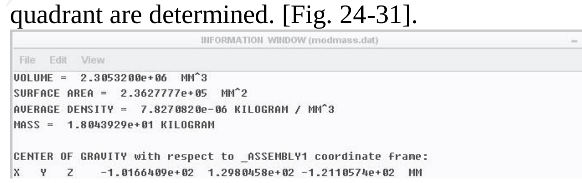

Figure 24. Weight and C. G. of fixture in Quadrant I

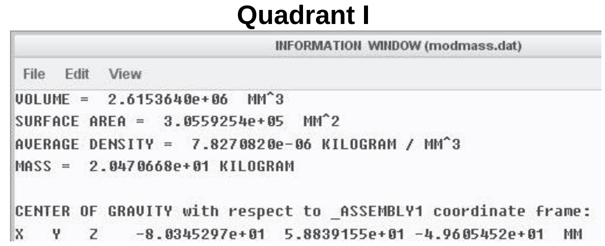

Figure 25. Weight and C. G. of fixture in Quadrant II

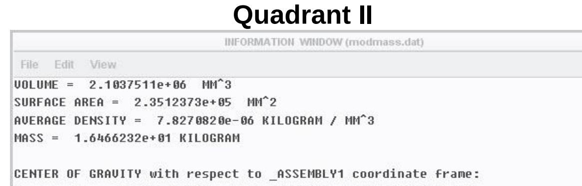

Figure 26. Weight and C. G. of fixture in Quadrant III

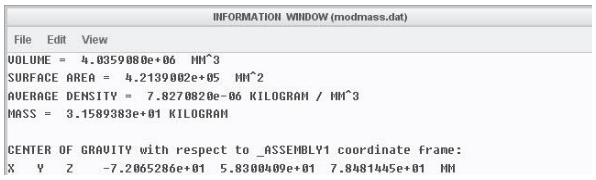

Figure 27. Weight and C. G. of fixture in Quadrant IV

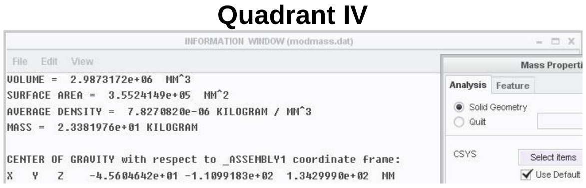

Figure 28. Weight and C. G. of fixture in Quadrant V

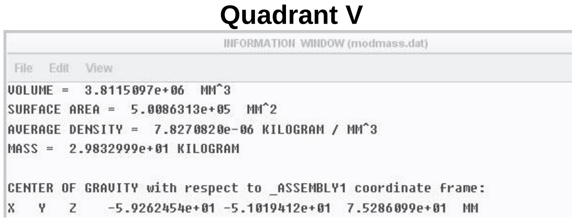

Figure 29. Weight and C. G. of fixture in Quadrant VI

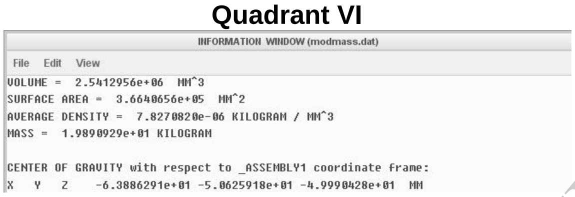

Figure 30. Weight and C. G. of fixture in Quadrant VII

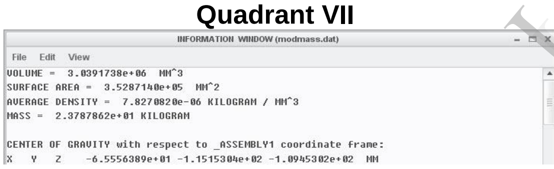

Figure 31. Weight and C. G. of fixture in Quadrant VIII

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

Table 11. 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	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

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 12].

Table 12. 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	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**

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].

Table 13. Sum of moment of Inertia about X ($\Sigma m_i x_i^2$) 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**

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].

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
α	77.82353484^0

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

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

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

$$M = R\, r_{cm}^2$$
$$r_{cm}^2 = M / R$$
$$r_{cm} = 164.79 \text{ mm}$$

Thus the unbalanced mass is found to be 59.51 kg and its C. G. is situated at an angle of 77.82^o 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. Next section reports relative comparison of results obtained of three methods used for mass balancing of rotary fixture.

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

Parameters	Mass Balancing Method: IV Quadrant Method	VIII Quadrant Method	VIII Diamond Quadrant Method
Unbalanced Mass (kg)	24.75	59.78	59.51
Angle of C.G. of unbalanced mass	13.45^0	72.22^0	77.82^0
Distance of C.G. of unbalanced mass (mm)	342.33	159.11	164.79
Quadrant of unbalanced mass	III	II	II
Total mass of assembly	208.21 kg	243.24 kg	242.97 kg
assembly	233.12 kg		
Percentage Error	10.685	4.341	4.225

4. 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.

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 %.

5. References

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