DYNAMIC BALANCING OF CRANKSHAFT BY QUANTITATIVE & QUALITATIVE ANALYSIS

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Abstract : ***The most of industries face common problem of output variation after the manufacturing operation. This variation sometimes leads to MORE CYCLE TIME of work pieces and even it reduces productivity. Whatever the case, it involves either additional machining cost or more quality time is required for machining.***

To reduce the cycle time and increase productivity smoothly, we implemented Theory of constraints techniques and analysis like Why-Why analysis and Root Cause analysis. This technique helped us to find the WEAKEST LINK of the problem and to find the corrective measures for the problem. Implementation is on manufacturing of Crankshaft in Bharat forge company, to increase productivity.

I. INTRODUCTION

Bharat Forge Ltd, the flagship company of the $2.1 billion Kalyani Group and a leading global supplier of forged and machined components, has laid the foundation stone of its new plant, Centre for Advanced Manufacturing, at Baramati on the outskirts of Pune in Maharashtra. Their Manufacturing products are Crankshaft & rings.

WHAT IS CRANKSHAFT???

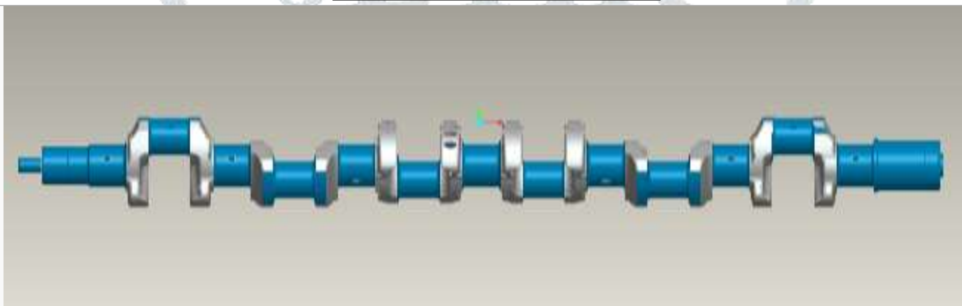


Fig 1.1 Model of Crankshaft

The **crankshaft**, sometimes casually abbreviated to *crank*, is the part of an engine which translates reciprocating linear piston motion into rotation. To convert the reciprocating motion into rotation, the crankshaft has "crank throws" or "crankpins", additional bearing surfaces whose axis is offset from that of the crank, to which the "big ends" of the connecting rods from each cylinder attach.

It typically connects to a flywheel, to reduce the pulsation characteristic of the four-stroke cycle, and sometimes a torsional or vibrational damper at the opposite end, to reduce the torsion vibrations often caused along the length of the crankshaft by the cylinders farthest from the output end acting on the torsional elasticity of the metal.

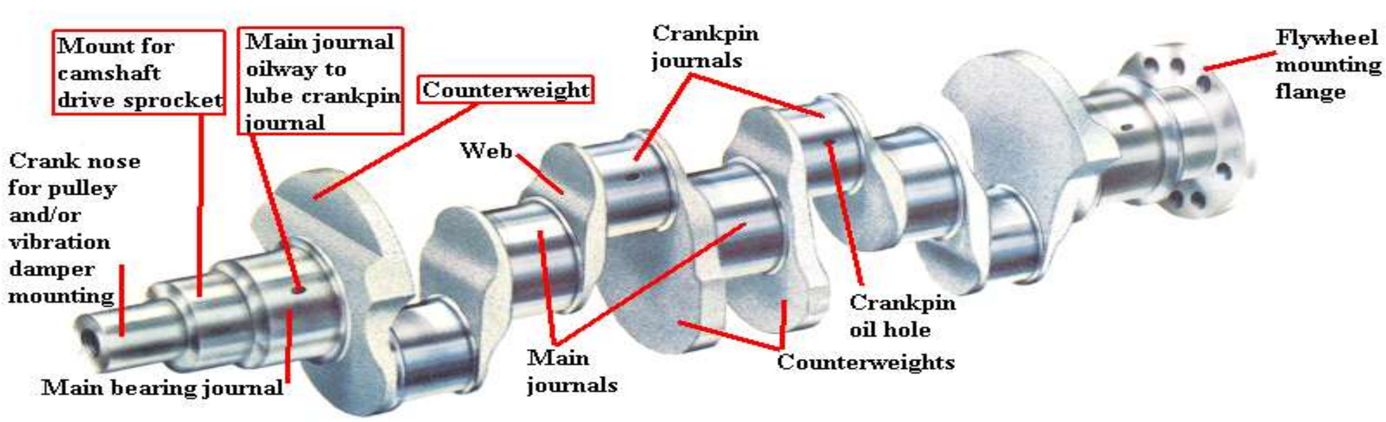


Fig1.2. Detail of Crankshaft

II. PROBLEM IDENTIFICATION

As per definition and steps of Theory of constraints, we checked and revealed the entire sequence of operation and concluded that the line is unbalanced due to cycle time. The following are observation table made for reference:

Operation No.	Operation Name	Cycle Time(Minutes)	Remark
1	Facing & Centering	3	
2	Rough Turning	_	
3	Axis To Axis Turning	5.30	
4	All Pin Milling	6	
5	Drilling Of Oil Holes	6.58	
6	Web Dibber & Oil Hole Intersection De-burr	2	
7	Pre Washing	3	
8	. Induction Hardening-	8	
9	Tempering	8	
10	Short Blasting	5.20	
11	End Bore	5.30	
12	All Pin Finish Grinding	6.50	
13	Journal Grinding	6.40	
14	God (Gear End Diameter) Grinding	5.55	
15	End Operations	6.30	
16	Fod (Flange End Diameter) Grinding	5	
17	Finish Bore	3.50	
18	Key Way And Web Sloting Operation	4.50	
19	Mpi (Magnetic Partical Inspection)	5	
20	Oil Hole Polish Chamfer & Dowel Pin Assembly	2	
21	**Dynamic Balancing**	**10**	**Cycle Time To Be Reduced**
22	Final Inspection	2	
23	Super Finishing	6.20	

Table 2.1 Cycle Time

<u>END RESULT:</u>

As per above observation table, we find that the cycle time (10 minutes) of dynamic balancing operation is more. The corrective action is to be carried out.

- **<u>How to load the crankshaft on the Dynamic balancing machine</u>**

1. Load the job keeping **FOD** face towards coupling adaptor and by hook Pin 2-3 as shown in fig:

2. Rotate adptor to match the Spindle '0' angle mark position.

3. Rotate the component so that P2 & P3 horizontal & towards operator side.

4. Align the coupling adptor at FOD face & dowel holes manually.Check the proper fitment of coupling locking screw of adaptor.

5. Ensure the parameters of SC drill Ø10mm before starting the cycle RPM=1100 & Feed=100mm/min.
6. Start the cycle by pushing LH & RH PB simulteniously provided at infront of m/c pendant.

7. Ensure proper coolant flow at drilling position.
8. After end of the cycle if ABRO screen shows green & OK.
9. Release Adaptor lock screw to remove coupling carefullyas shown below picture..

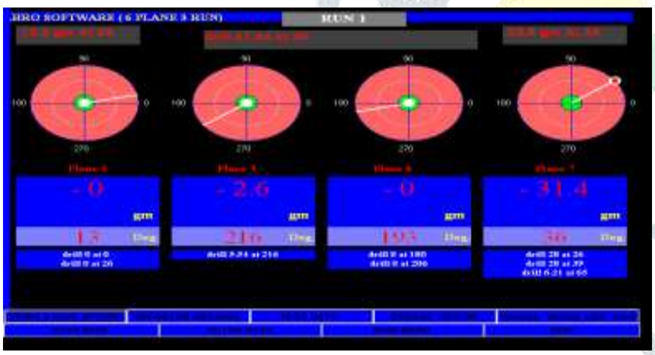
10. Punch **'B'** mark on the job as per MQP.
11. Unload the job.
12. After machining of first component, inspect all required dimensions as per control plan and Write down the inspection readings in check sheet.

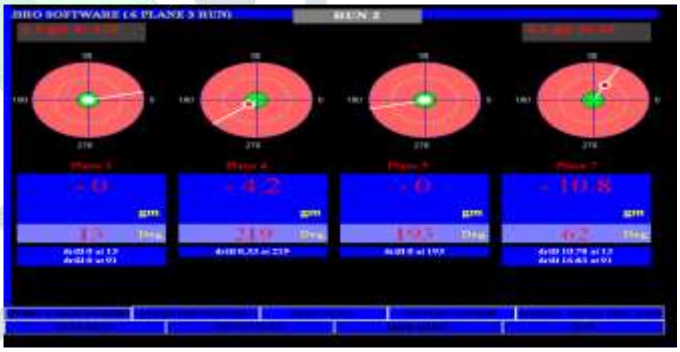
    If ok start the product

SCREEN -SHOTS

The following are the screen shots shows that the amount of unbalanced of crankshaft with respect to angle at particular planes which is useful to make crankshaft balance by removing material through drilling at particular angle.

RUN 1: The below image depict that the initial unbalance condtion of crankshaft



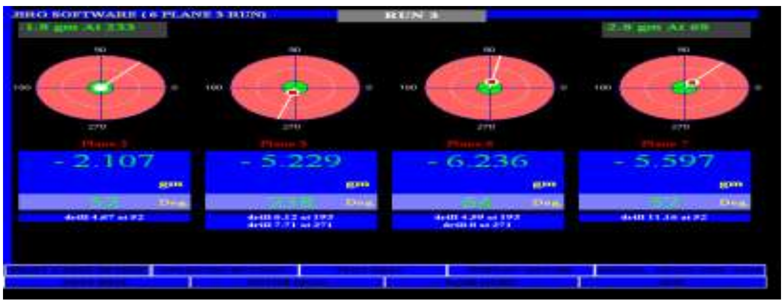


RUN 2:

The below image depict the position achieved by drilling operation

RUN 3:

As per previous run, the crankshaft is still not in balanced condition (upto 3 gms), so there is need to drill to remove the excess material.

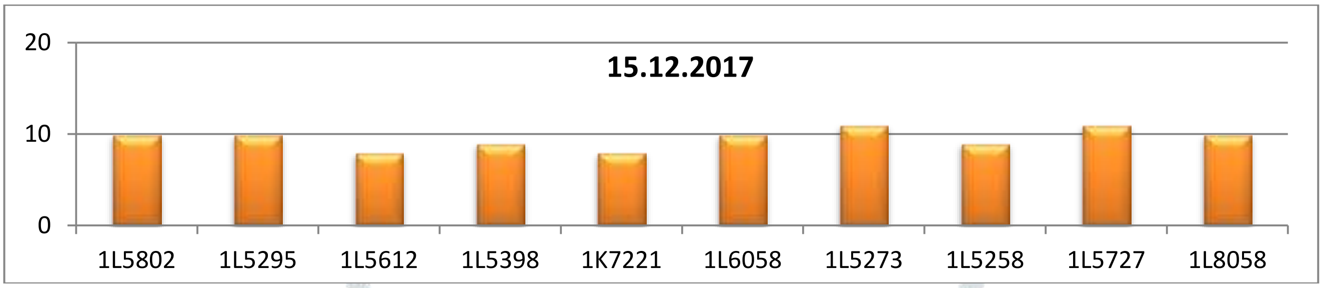


DYNAMIC BALANCING READINGS (BEFORE)

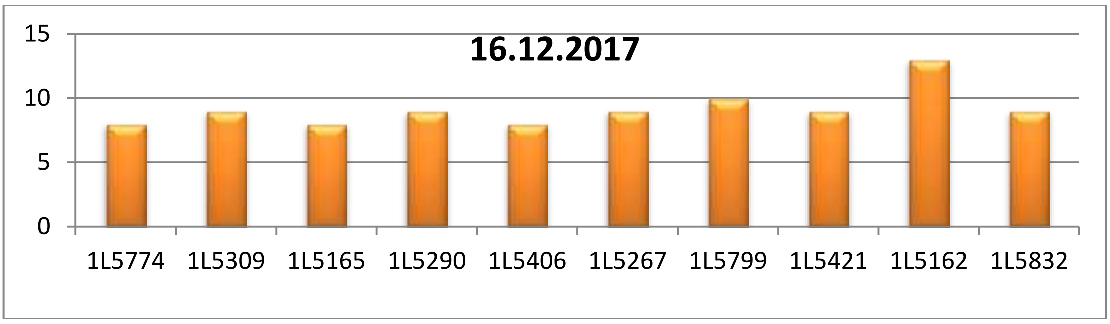
The following are the readings of the production trial run of 10 crankshafts on fifteen days basis:

D3678 MD3 ABRO AUTO M/C BALANCING READINGS						15.12.17	
SR. No.	Part No.	Amount	Angle	Amount	Angle	Cycle time	CT In sec

	(NEW)					min/sec		
						Min	**Sec**	
1	1L5802	53	94	51.4	71	10		600
2	1L5295	50.8	83	38	58	10		600
3	1L5612	24.8	97	19.4	47	8		480
4	1L5398	41	96	37.4	62	9		540
5	1K7221	52	59	64	38	8		480
6	1L6058	50	101	41.8	85	10		600
7	1L5273	60.4	112	44.2	90	11		660
8	1L5258	43	90	45.4	57	9		540
9	1L5727	57	97	50	71	11		660
10	1L8058	50	101	41.8	85	10		600
				Avarage cycle time in min.		**9.6**		576

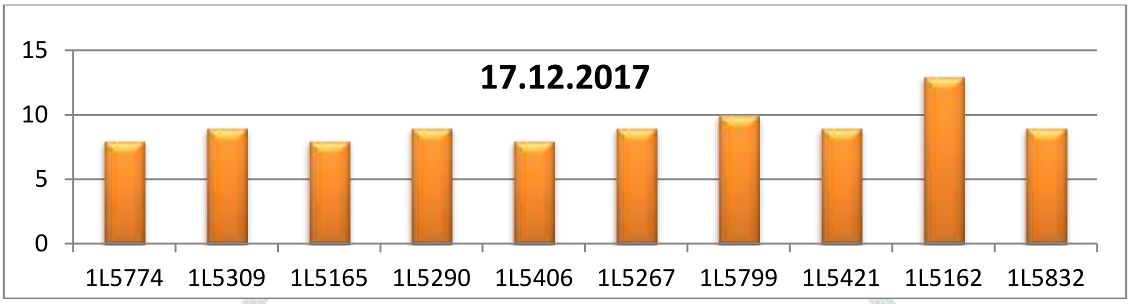


D3678 MD3 ABRO AUTO M/C BALANCING READINGS 16.12.17								
SR. No.	**Part No. (NEW)**	**Amount**	**Angle**	**Amount**	**Angle**	**Cycle time min/sec**		**CT In sec**
						Min	**Sec**	
1	1L5774	43	98	29.8	59	8		480
2	1L5309	47.8	117	32.8	86	9	7	547
3	1L5165	40	101	32.6	57	8	1	481
4	1L5290	45	117	36.4	79	9	3	543
5	1L5406	36.8	106	40.4	65	8	35	515
6	1L5267	48.8	119	38.2	89	9		540
7	1L5799	57.8	92	60.2	65	10		600
8	1L5421	48.6	94	44.2	61	9		540
9	1L5162	47.8	115	27.6	92	13	52	832
10	1L5832	36.6	99	37.6	61	9	35	575
				Avarage cycle time in min.		**9.4**		565



D3678 MD3 ABRO AUTO M/C BALANCING READINGS 17.12.17								
SR. No.	**Part No. (NEW)**	**Amount**	**Angle**	**Amount**	**Angle**	**Cycle time min/sec**		**CT In sec**
						Min	**Sec**	
1	1L5399	37.8	102	36.4	57	8		480
2	1L5799	57.8	92	60.2	65	10		600
3	1L5421	48	94	44.2	61	9		540

4	1L5782	52.4	109	34.8	80	12		720
5	1L5767	62.4	90	49.4	65	8	5	485
6	1L5726	65.8	95	52	73	11	10	670
7	1L5484	23.6	95	24.6	38	6	40	400
8	1L5042	59	105	50.6	92	11	10	670
9	1L5221	61.6	84	52.4	65	7	30	450
10	1L0046	49.4	100	37.8	25	8	58	538
				Avarage cycle time in min.		**9.3**		555



END RESULT:

As per the TOC method the above mentioned result is obtained, so we conclude that the cycle time (08 - 10 minutes) of dynamic balancing operation is more which act as ***the weakest link****, it is to be minimized or eliminated completely. It is necessary to find out the exact root cause of the unbalancing of crankshaft.*

III IMPLEMENTATION OF TECHNIQUES

The cycle time is required to be minimized, but the root cause of more cycle time is not yet calibrated. So there is need of analyzing the root cause by implementation various techniques in order to reduce the cycle time.

The following are the steps to be carried out to find out the core of the problem related to cycle time:

- **WHY – WHY Analysis**
- **ROOT CAUSE ANALYSIS**

WHY-WHY ANALYSIS

What is a why-why analysis[1]?

It is a method of questioning that leads to the identification of the root cause(s) of a problem.

What is the purpose of a why-why analysis?

A why-why is conducted to identify solutions to a problem that address it's root cause(s). Rather than taking actions that are merely band-aids, a why-why helps you identify how to really prevent the issue from happening again.

How to conduct a why-why analysis?

A why-why is most effective in a team setting or with more than one person involved. Capture the input on a flipchart or a simple spreadsheet like the one below.

1. First start with the problem you'd like to solve. Then ask, "Why is x taking place?" You will end up with a number of answers. Jot these down.
2. Repeat the process for each of the answers to the first question.
3. Repeat the process for each of the answers to the second 'why' and continue until you've asked why 5 times.
4. When you've hit the 5th why, you usually have determined some root causes. Now you can identify specific action plans to address those root causes.

How to make the why-why effective?

- **Involve the right people – it** helps to have those that are familiar with the process and the problem in the room so they are able to answer why something happened. It is also helpful to have someone with a fresh eye participate – often they ask questions that help those involved in the problem extract the real reasons something happened.
- **Avoid blaming – look for systemic problems.** You are looking for systematic solutions to the problem. Blaming an individual ends up only making people feel bad. If someone didn't turn the right valve, ask the question "What could have helped the person turn the right valve?" Could improvements in a procedure or labeling the valve have helped the individual?
- **Get creative** – what systematic solutions might address the problem? Allow people to brainstorm and identify potential actions to address the issue. Later, go through the potential actions to identify the solutions that will yield the most effective results.

ACTUAL ANALSIS DONE:

1. ***Why cycle time is more required for dynamic balancing machine?***
   Ans. *Material removal by drilling hole is more.*
2. ***Why Material removal by drilling hole is more?***
   Ans. *Unbalance amount of material at different angles is more.*
3. ***Why time required for drilling hole is more?***
   Ans. a) whether speed, feed rate of pre programmed CNC machine is low???

➢ *CNC special purpose Machine is skillfully programmed by programmer so no chance of further making any change in program*

b) Whether drilling tool material is not up to required mark???

➢ *High grade of carbide tipped tool is used so it ensure better drilling operation so no need to change the material or grade of drill bit.*

END RESULT:

*After analyzing the entire process by material and machine specification through **WHY WHY ANALYSIS**, we concluded that the tool material and machine are fool proof no required for change. So it is necessary to undergo the **ROOT CAUSE ANALYSIS** to reach the exact core of the problem.*

ROOT CAUSE ANALYSIS

Root cause analysis (RCA) is a class of problem solving methods aimed at identifying the root causes of problems or events. Root Cause Analysis is any structured approach to identifying the factors that resulted in the nature, the magnitude, the location, and the timing of the harmful outcomes (consequences) of one or more past events in order to identify what behaviors, actions, inactions, or conditions need to be changed to prevent recurrence of similar harmful outcomes and to identify the lessons to be learned to promote the achievement of better consequences.

The practice of RCA is predicated on the belief that problems are best solved by attempting to address, correct or eliminate root causes, as opposed to merely addressing the immediately obvious symptoms. By directing corrective measures at root causes, it is more probable that problem recurrence will be prevented. However, it is recognized that complete prevention of recurrence by one corrective action is not always possible.

Root cause analysis is not a single, sharply defined methodology; there are many different tools, processes, and philosophies for performing RCA. However, several very-broadly defined approaches or "schools" can be identified by their basic approach or field of origin: safety-based, production-based, process-based, failure-based, and systems-based.

- Safety-based RCA descends from the fields of accident analysis and occupational safety and health.
- Production-based RCA has its origins in the field of quality control for industrial manufacturing.
- Process-based RCA is basically follow-on to production-based RCA, but with a scope that has been expanded to include business processes.
- Failure-based RCA is rooted in the practice of failure analysis as employed in engineering and maintenance.
- Systems-based RCA has emerged as an amalgamation of the preceding schools, along with ideas taken from fields such as change management, risk management, and systems analysis.

ACTUAL ANALYSIS DONE:

The following observation table shows that whether any operation can affect the balancing of crankshaft:

Sr no	Operation	Details	Effect of balancing
1	Dynamic balancing	• Check unbalance amount(kg) & angle • Remove material by drilling holes to balance the component	• Perfect balancing • Require more time
2	Drill hole polish & dowel assembly	• Just polishing by polish paper	• No fffect because less material removal
3	MPI	• Check crack & detect it	• No effect
4	Key way & web slot	• Milling of key & web slot by SPM	• No effect
5	Finish bore	• By SPM	• No effect because less material removal at circumference
6	FOD grinding	• Removal material by grinding	• No effect because less material removal at circumference
7	End operation	• Drilling,tapping & reaming of holes	• No effect because material removal at both end as same amount
8	GOD grind	• Grinding & removal of material	• No effect because less material removal at circumference
9	Journal grinding	• Less material removal & smooth grinding	• Not effect
10	All pin finish grinding	• Less material removal & smooth grinding	• No effect
11	End bore	• Boring operation drill the step bore at FE	• No effect
12	Shot blasting	• Removal scale and dust	• No effect
13	Tempering	• Heat treatment for stress removal	• No effect
14	Induction hardening	• Heat treatment for hardening	• No effect
15	Washing	• Clean the job	• No effect
16	Web deburr & oil holes	• Less material removal by polish	• No effect

17	SOH & IOH	• Drilling of oil holes at SOH & IOH	• Not effect
18	Pin milling	• Removal of material on pins by milling	• No effect because less material removal at circumference
19	Axis to axis turning	• Less material removal on journal	• No effect because less material removal at circumference
20	**Facing & centering**	• **Centre hole drilling & facing at both end** • **Center holes defines centre axis of job**	• **Axis may be affected on unbalance the job**

Table 3.1 Root cause analysis

END RESULT:

As per above analysis, we come to conclusion that the entire axis of the component is defined by the facing and centering operation. So there is need to focus on the respective operation as they are the base operation of entire procedure in order to get the mass balanced crankshaft.

IMPROVEMENT TECHNIQUES

In this section, we carried out the analysis and improvement on trial and error basis to achieve the goal of the project.

Analysis of problem related facing and centering

The facing and centering operation depends upon the following factors:

1. **The position of center drill bit and facing inserts.**

Fig 3.1 the position of center drill bit and facing inserts

- The position of the drill bit and facing inserts outside from adaptor depends upon the rate of material removal from the both sides of the components.
- The position is acquired by either locking the lock nut or axial movement of shaft as per the rate of material removal.
- Fix the position of the tool and shaft on the trial & error basis.

Possible causes of not moving the "V" block:

1. Studs are jammed in holes of bushes because of rust and corrosion
2. Spring pressure may be low
3. May be the studs are bended
4. Spring gets blocked in the holes

The following are the observation made after removal of "V" block for further corrective measures:

1. Studs are bended and that observed visually.
2. Holes of bush oversize because of that the center distance between two bushes shifted

Corrective action taken:

After having discussion with engineering department regarding the problem, they allowed us to design and manufacture the new bush with stud rod. In this task tooling department assisted us.

2.Problem faced during the assembly of bush and rods:

During the assembly of bush and rods, the axes of bush and rod were mismatching. On the Trial & error basis we tried to assemble some new parts and old parts to achieve requirements.

Fig 3.2 Assembly of bush and rod

Observation:

Sr. no	Job No	Total Height	Centre height	Run out
1	2B0401	521.0	242.3	0.6 / 0.8
2	2B0402	521.1	240.9	0.7 / 0.8

3	2B0403	521.1	241.7	1.2 / 0.8
4	2B0404	521.2	241.5	1.0 / 0.8
5	2B0405	521.1	241.4	0.7 / 0.9

Table 3.1 observation table wrt Trial and error

<u>Result:</u>

- After carrying out the necessary step, we observed that vertical sliding "V" block does not affect on balancing after its transverse movement.
- But it affects on the center height & total height of crankshaft.

3<u>"V" block locator for location and clamping (fixture)</u>

- During the operation, this "V" block gives the exact location and clamping to the crankshaft.
- This also helps to define the axis of the component because above fixture exactly locates the job while carrying out the operation.
- **<u>Corrective action:</u>**
- After discussion with engineering department and higher authorities we concluded that with respect to Parallel axis theorem, we can shift centre axis of crankshaft by inserting the shims (thin plates) between "V" block and base structure on trial and error basis.

- On trial & error basis, we changed the thickness of shim in order to reach the exact centre axis of the component and took trials of job rotating between two movable centres.

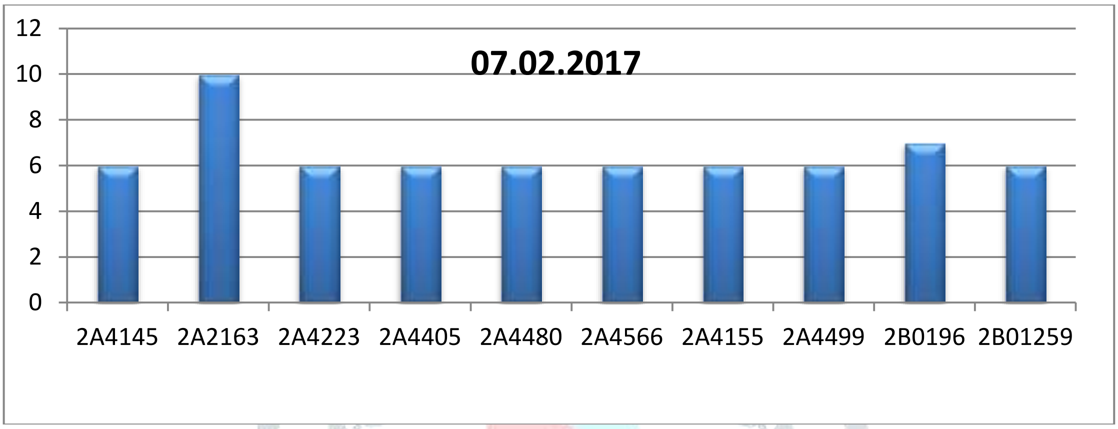
- Hold the job be nters and give a slight movement in circular motion, then it is noted that when the job comes to rest in descending motion then it is well balanced crankshaft, but if it comes in a speedy motion to the rest then the crankshaft is in unbalanced state.
- With the respect to above statement, we inserted certain amount of thickness of shim in order to achieve well balanced job.
- After adding the 1.8mm thickness of shim, we came to conclusion it gives the exact position of centre of axis **<u>because when rotating a job hold between two centers came to rest in descending motion at any degree.</u>**
- So we started monitoring of balancing of component on dynamic balancing machine

<u>DYNAMIC BALANCING READINGS (AFTER)</u>

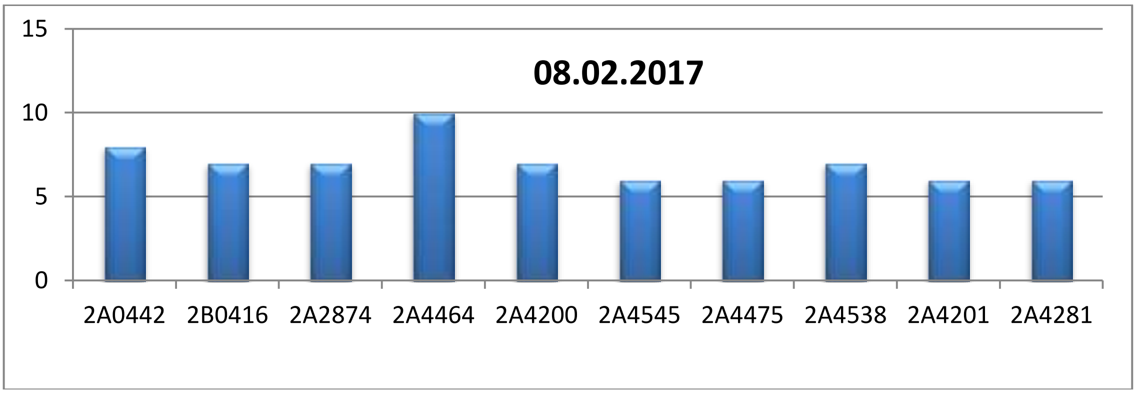
The following are the readings of the production trial run of 10 crankshafts on fifteen days basis:

D3678 MD3 ABRO AUTO M/C BALANCING READINGS						07.02.2017	
SR. No.	**Part No. (NEW)**	**Amount**	**Angle**	**Amount**	**Angle**	**Cycle time min/sec**	**CT In sec**

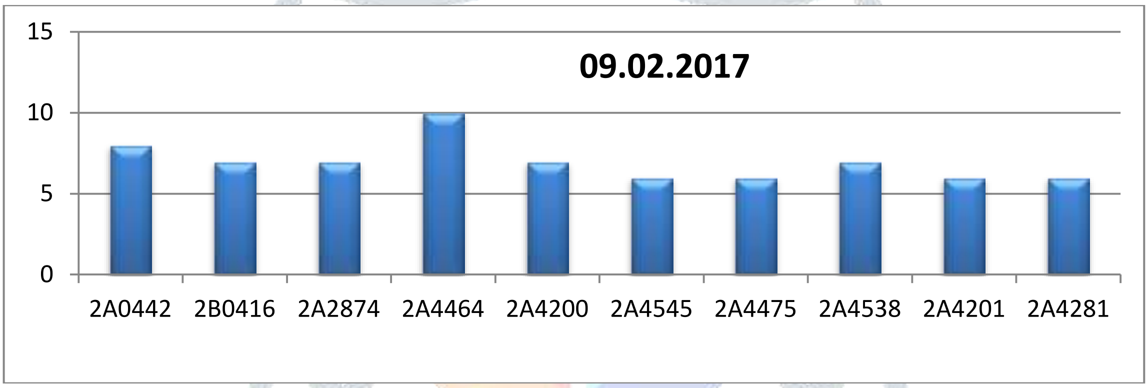
						Min	**Sec**	
1	2A4145	20	140	21	45	6	34	394
2	2A2163	75	201	20	224	10	16	616
3	2A4223	21	152	13	23	6	23	383
4	2A4405	13	91	34	28	6	16	376
5	2A4480	24	37	35	13	6	1	361
6	2A4566	30	72	28	49	6	57	417
7	2A4155	16	248	25	331	6	10	370
8	2A4499	29	85	23	33	6	17	377
9	2B0196	30	140	33	67	7	40	460
10	2B01259	24	121	29	46	6	5	365
				Avarage cycle time in min.		**6.9**		412



D3678 MD3 ABRO AUTO M/C BALANCING READINGS						**08.02.2017**		
SR. No.	**Part No. (NEW)**	**Amount**	**Angle**	**Amount**	**Angle**	**Cycle time min/sec**		**CT In sec**
						Min	**Sec**	
1	2B0338	20.8	151	30.1	36	6	18	378
2	2A4471	16.6	46	31.2	7	6	33	393
3	2A4286	24.2	108	29.6	62	6	3	363
4	2A4312	36	164	35.6	65	7	22	442
5	2B0131	15.4	153	20	17	6	29	389
6	2B0290	20	130	35	41	9	54	594
7	2B0194	19.8	154	15.6	37	7	11	431
8	2B0156	24	110	28	55	6	3	363
9	2B0365	26.2	118	31.4	58	6	11	371
10	2B0163	11.4	118	25	24	4	47	287
				Average cycle time in min.		**6.7**		401



D3678 MD3 ABRO AUTO M/C BALANCING READINGS 09.02.2017								
SR. No.	**Part No. (NEW)**	**Amount**	**Angle**	**Amount**	**Angle**	**Cycle time min/sec**		**CT In sec**
						Min	**Sec**	
1	2A0442	18	114	26.2	48	8	17	497
2	2B0416	24.6	118	34.6	50	7	0	420
3	2A2874	23.2	184	23.2	137	7	31	451
4	2A4464	18.2	180	24.6	35	10	28	628
5	2A4200	7.8	168	20	10	7	11	431
6	2A4545	18.8	126	25.8	45	6	35	395
7	2A4475	33.4	106	31	67	6	49	409
8	2A4538	24.2	96	24.8	50	7	25	445
9	2A4201	8.4	225	27.4	353	6	56	416
10	2A4281	26	116	18.4	76	6	49	409
				Avarage cycle time in min.		**7.5**		450



END RESULT:

*From the above graph, we noted that the cycle time of the dynamic balancing for one component is reduced **from 8 – 12 minutes to 5 – 7 minutes by shifting axis of the component.***

IV. CONCLUSION

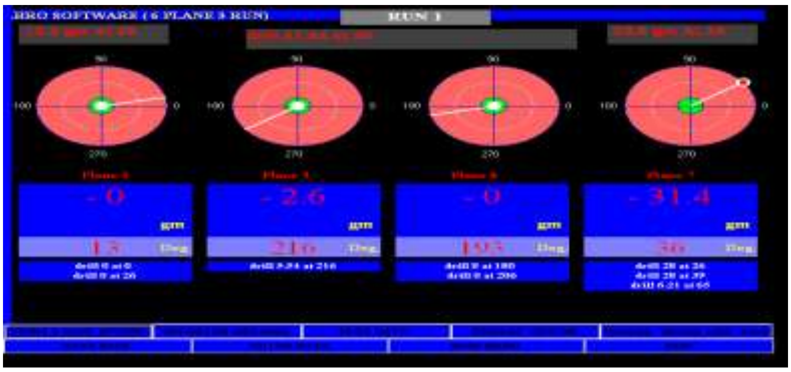
*As per the improvement techniques and analysis like **WHY-WHY analysis and Root cause analysis**, the core of the problem was defined and the corrective action was taken as per. **The main highlight was the cycle time which act as weakest link is now being controlled within limits.***

Secondly, balancing of cylindrical component i.e. crankshaft is depended upon its axes. This implies that there is a relationship between the material removal and center of axis. Here the the entire axis of the component is defined by the facing and centering operation. So we focused our target on these base operations and achieved mass balanced crankshaft.

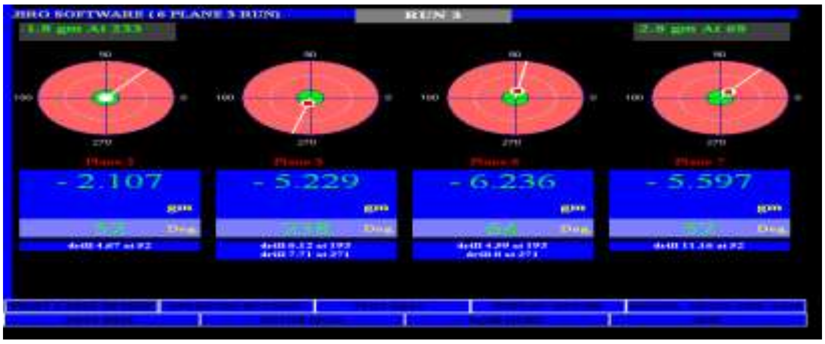
Lastly, we conclude that the entire project work done increased productivity with minimizing the cycle time as shown in the below graph

SCREEN -SHOTS

Before



After



INSERTED SHIM

Before

After

V. Acknowledgment

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VI. References

Manuals & technical paper:

[1] Bharat forges MCD manuals
[2] Design data book
[3] Why-why analysis – Cornell management system
[4] Root cause Analysis-Edward J. Dunn, MD, MPH and Craig Renner, MPH
[5] VA National Center for Patient Safety

Books:

[1] Theory of machines – S.S.Rattan
[2] A textbook of Internal combustion Engine – V. Ganesan
[3] Jigs & Fixtures – P.H. joshi
[4] Theory of constraints – Eliyahu Goldratt