ROBOTIC GRINDING FOR COMPLEX FERROUS CASTINGS – A COMPARATIVE STUDY OF CONCEPTS, SELECTION OF OPTIMAL SOLUTIONS

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INTRODUCTION -

Sameer Kelkar -
Silver Medalist and Graduate of IIT Bombay, and MS in Robotics from University of California, Berkeley, is CEO and R&D Head of Grind Master Machines Pvt. Ltd, pioneers Robotic Metal Finishing Technologies. Sameer Kelkar is venturing into new horizons of Robotic Applications such as Grinding, Deflashing, Fettling, and Machining. This article is written using research, data and application experience over the past 10 years.

PAPER SUMMARY -

The manufacturing industry is undergoing a revolution in productivity, quality, and Environmental and Safety norms. The foundry sector in general and ferrous casting industry in particular, has been slower than other manufacturing sectors to adopt robotics as a way forward. Chip and Grind is a particularly dirty application requiring lots of manual labor working in unsafe and unhealthy conditions. A transformation is upcoming in this sector, with the advent of robotic grinding for ferrous castings.

Robotic Grinding Machines are built with mainly 2 concepts -

Concept 1 – Robot holding Spindles – Castings on Fixture – referred to as Rx

Concept 2 – Robot holding castings – Spindles in Toolbox – referred to as Ry

Selection of the correct machine concept for the variety of castings produced by a foundry is key in determining the success of a solution technologically and economically.
This article explores the key concepts in making this selection.

ROBOTIC GRINDING OF COMPLEX FERROUS CASTINGS

Fettling is a process in the iron casting industry that is labor intensive. It is estimated that around 25-30% of all Foundry Manpower is in the Fettling/Grinding operation.

Automatic grinding brings several key benefits including increased productivity (5-8 fold), improved quality, and a healthy and safe working atmosphere.

Selection of the right concept is key in determining success of a solution.

Various factors play a key role in making this choice -

1. Casting sizes/weights
2. Number of casting variants – Families of castings
3. Grip-ability of the castings
4. Variety of operations on the castings
5. Automation requirements for load/unload of castings into the machine

This article explains the pros and cons of the concepts used for robotic grinding (Concept 1 and 2) considering above factors and how a selection of solution concept might be made.

Why not CNC Machine type solution for complex Castings ?

CNC Grinding Machines for Fettling are sometimes used for Simple shaped Castings. However these are not appropriate for complex castings. A detailed study of this is not in scope of this paper however the basic reasons are as follows –

1. Insufficient Flexibility in no. of axis
   (typically 3-5 axis)

2. Insufficient no. of tools for complex Grinding

3. Lacking software capabilities to manage casting variations

For these reasons it is recommended to use CNC grinding machines for simple castings such as -

1. Brake Disc/Drum
2. Limited Face Grinding Operations in Cylinder Heads / Blocks

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BASICS OF ROBOTIC GRINDING

CASTING – CASTING VARIATION MANAGEMENT –

Multiple technologies are used in Machines for managing the variations from casting to casting.

These include –

Force Control Methods – Active/Passive
Adaptive Motion Methods – Robot Motion Modification/Grinding Process Modification

BASICS OF ROBOTIC GRINDING

Robot load Capacity

The wrist is the critical unit of an Industrial Robot from a Grinding/Machining Load Perspective.

2 Critical factors to be considered while ensure a good Factor of Safety (FOS > 2) in selection of Robot and Machining / Grinding Spindles –

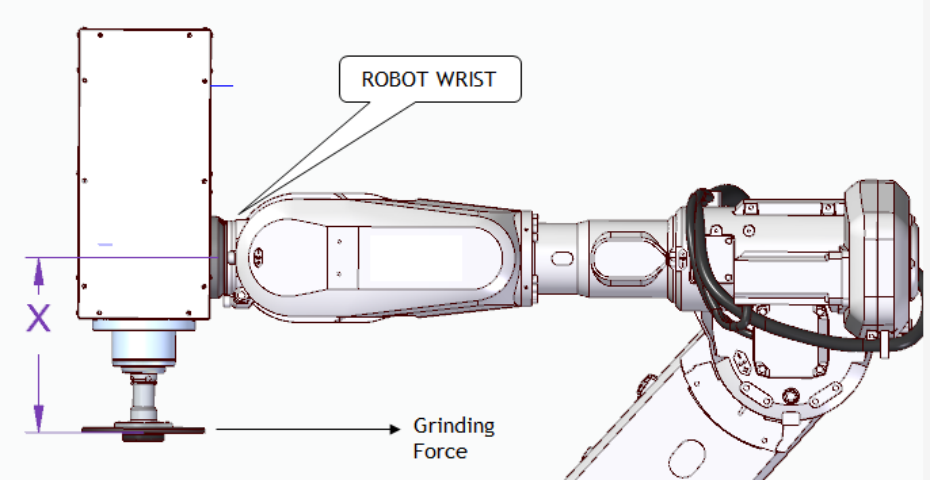
ROBOT WRIST MOMENTS

Critical Determining Factors in Applied Wrist Moments –

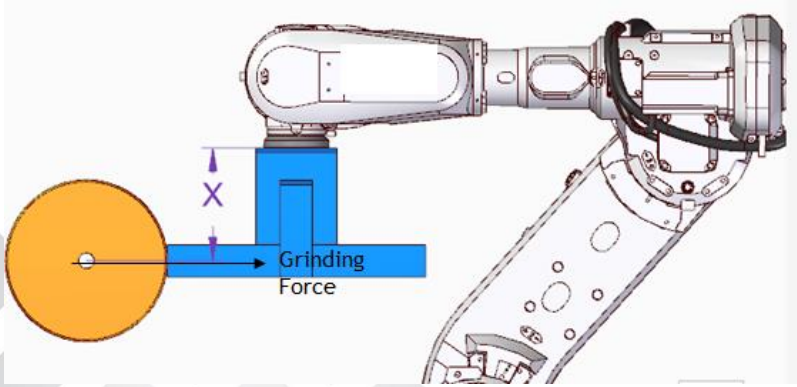
1. Grinding Force – Based on Spindle power / wheel size
2. Distance from Robot Wrist – Z and L as shown in chart below

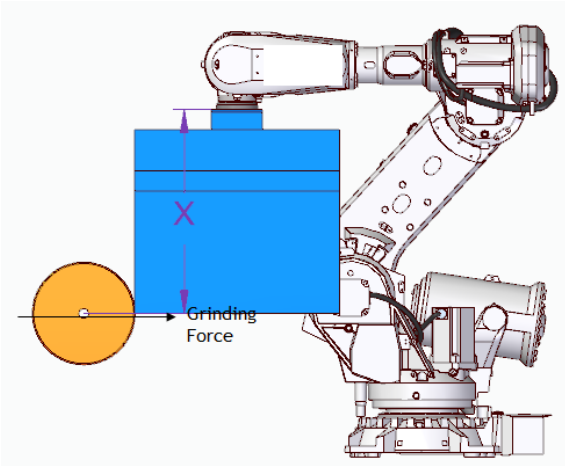
Note this distance is Fixed in Rx concept, but is variable as per Casting size in Ry concept.

BASICS OF ROBOTIC GRINDING



Forces Acting at Constant Distance X in Rx Concept

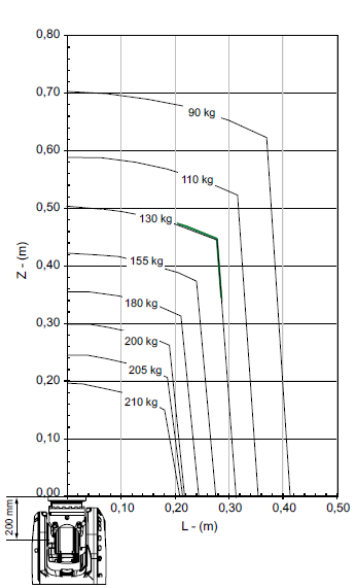


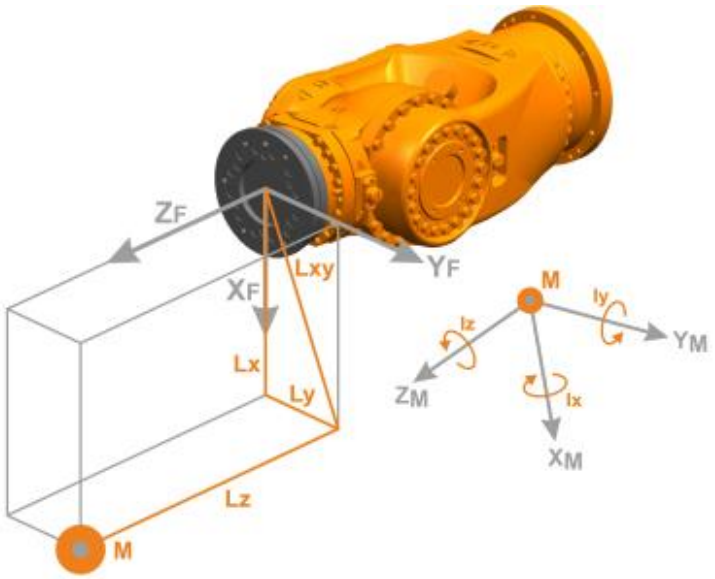


Forces Acting at Variable Distance X in Ry concept

BASICS OF ROBOTIC GRINDING

Note that the capacity of the robot drops very steeply beyond a certain L value. Hence it is highly recommended to design for the load to be as close to the wrist as possible.





MACHINING ACCURACY –

Robot Positioning Repeatability – ranges from 20 microns to 50 microns depending on Robot Size
Robot Path Accuracy – ranges from 0.5mm to 2mm depending on Robot size

Various Other factors affecting accuracy such as Fixturing Accuracy, Casting Dimensional Sensing Accuracy and Tool Diameter accuracy are normally within 0.5mm

Based on industry observations a general machining accuracy in the range of 1mm to 3mm can be expected. This accuracy is affected by the size and dimensional accuracy of the castings themselves.

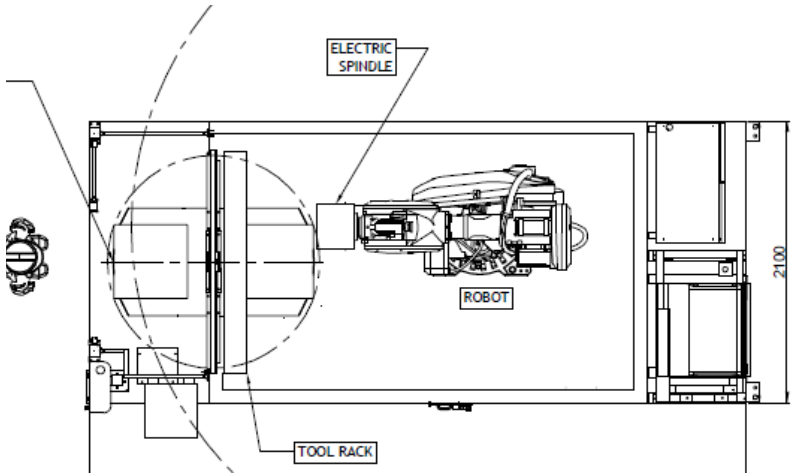
MACHINING PROCESSES

Robotic manipulators are very versatile mechanisms. However, they do not compare to the rigidity and stiffness of machine tooling. Manipulators are lighter weight, and their dampening characteristics are not as good as machine tools constructed of casting/fabricated elements. Machining processes such as milling require a rigid structure and therefore face several limitations with robots. These limitations are evident when machining hard materials. Grinding processes are much more suitable for robotic applications, especially on hard casting materials such as ferrous castings. Grinding is more forgiving than machining as it generates lesser vibrations due to multiple cutting points.

Grinding tools need to be selected specific to the material being processed.

Rx – Robot holding spindle

In this concept of Machines the Castings are fixtured on a Machining Table, and the Robot holds the spindles and performs the machining tasks.



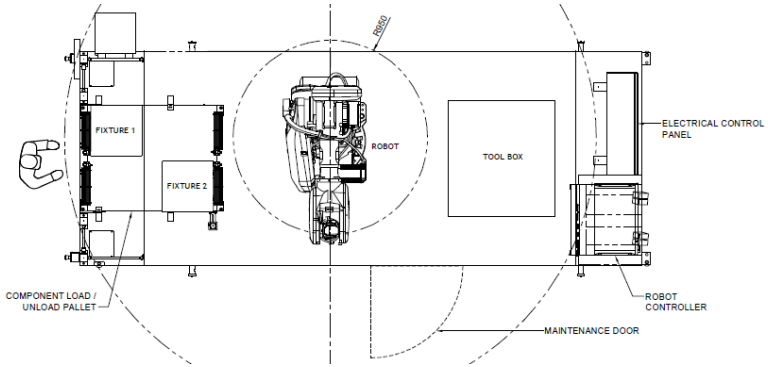
The following variations can be considered for production requirements –

1. Pallet Exchanger or Multiple Machining Tables to mask Load/Unload Times
2. Tool Changing Spindles to have multiple tools for operation
3. Spindle changers to have multiple spindles for operation

Ry - Robot holding castings

In this concept of Machines the Castings are Gripped in the Robot, and spindles are mounted in a Toolbox.
The Robot performs the machining tasks by taking the castings to the tools.

A Typical layout is below -



The following variations can be considered for production requirements –

1. Multiple Load/Unload Options including Fixtures / Pallet Exchanger / Conveyor
2. Multiple Heads/Spindles in the Toolbox
3. Automatic Gripper Changer Systems for Quick Setup change

SUMMARY OF PROS AND CONS

Machine Concept	Rx Robot Holding Spindles Casting loaded on Machining Table with Fixture	Ry Robot Holding Casting with Gripper Multiple Spindles inside TOOLBOX	Remarks
Robot Size	Variable from 200kg to 500kg Payload	Variable from 20kg to 300kg Payload	
Investment Machine	**Typically Higher**	**Can be economical esp for small castings**	
Weight Limitations	50kg – 5tons Configurable	2kg – 100kg Configurable	Based on usage of Standard Robots
Cycle time	Slower for Multi Tool Operations. OK for Single Spindle Operation like Gate Cutting	Faster than RMT for Multi Tool Operations by 20-25% Due to lesser Air Cut Time	
Grinding Process Speed	Slower than Ry for castings with less flash	Slower than Rx for castings with heavier flash	
Non Value Added Time	Higher Times for Tool change	Lower Times for Tool change	
Typical Grinding Power Used	10 – 40 KW	2 – 10KW	Higher Power when Rigid Fixturing is used.
Investment Additional casting Variants	Low	High	
Setup Change	Change Fixture 7-10 min	Change Gripper 7-10 min Change Loading Nest 5-10min	
Load/Unload Options	Manual or Robotic on Fixture	Manual or Automated on Fixture / Pallet Exchange / Conveyor	Robot can handle parts easier
Automation of Load/Unload	Can be done with independent Loading/Unloading mechanism	Can be integrated into the machine with Robot Picking/Dropping casting from Transfer Line	
Space Usage	Compacter Need separate handling space	Larger Space per Machine Handling space can be saved	RMT is compacter
Multiple Machines Possibility	**Independent Machines can be connected with Additional Handling System**	**Interconnected Machines with Robots passing the Casting with Intermediate Fixtures saves lots of handling effort/cost**	

SUMMARY OF PROS AND CONS

Selection of Solution for a range of castings thus depends on various factors.

For mass produced Castings weighing less than 15kgs, a Ry Solution is normally better because –

1. Automatic load/unload with multiple parts in a pallet
2. Faster cycle times with multiple tools for 100% grinding

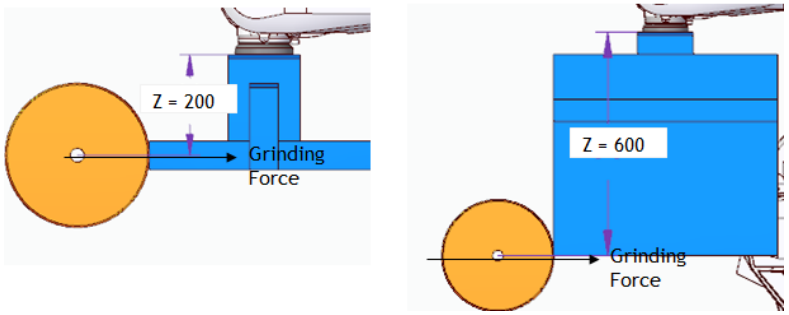
For batch produced castings weighing more than 100kgs, a Rx Solution is normally better because –

1. Faster and more economical Setup Change
2. Faster cycle times with heavier capacity spindles
3. Beyond 100kg the Ry solution is not feasible due to Robot Size limitations.

Between 15kgs and 100kgs is a GREY Area - where the Selection is dependent on various factors that impact the selection.

CASE STUDY – COMPARISON OF SOLUTION FOR COMPRESSOR CASTINGS

Compressor Castings like Rotor Housings, Bearing Housing are somewhat Cubical in shape and hence unsuitable to be grinded with Ry concept due to large Z Distances from the Wrist.



Grinding Forces in Ry concept create much larger moments on Wrist in Castings of Cubical shape

The below information is from a relatively flat casting which could be considered in both Rx and Ry concepts.

The castings in the below study had very heavy flash – almost 6-8mm at the root thickness. The Rx concept machine is able to grind much faster due to heavier machining power used. This is possible because the Robot wrist moments do not play a limiting role in applying forces as shown in the figure above. The Grinding Power used in Rx solution can be 3X of the Grinding Power used in Ry Solution.

CASE STUDY – COMPARISON OF SOLUTION FOR COMPRESSOR CASTINGS

The large casting variations (upto 3-4mm) also require a Sensing-pre-cycle.

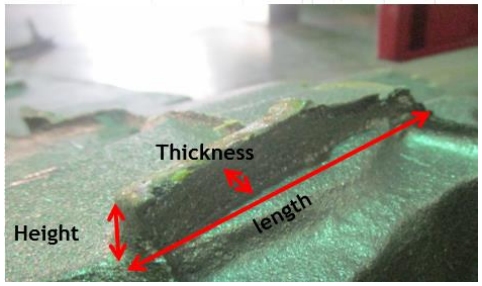
Typical operations include –

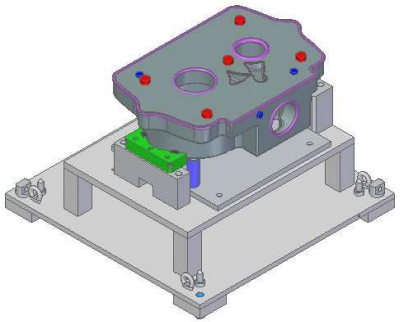
1. Gate Leftover Grinding
2. Parting Line Grinding on Sides

The above operations need typically 2 tools.

Casting Size – 290mm X 210mm X 150mm (height)

Weight – 22 kgs









CASE STUDY – COMPARISON OF SOLUTION FOR COMPRESSOR CASTINGS

	Robot Holding Spindles Rx	**Robot Holding Castings Ry**	**Remarks**
Total Cycle time	260 sec	437 sec	
Processing Time	193 sec	377 sec	Rx is much faster due to faster stock removal of heavy flash
Non Value Added Time - Load/Unload - Tool change - Sensing Cycle	67 sec	60 sec	
Variable Cost	INR 25/casting	INR 30/Casting	
Fixed Cost (considering 10 year life)	INR 12/casting	INR 16/casting	Higher in Ry due to higher cycle time
Application Features			
Load/Unload	Manual	Manual or Flexible Fixtureless Conveyor with Robotic Vision	
Setup change	Manual Fixture Change	Manual Fixture and Gripper Change	
Dust Collection	Inefficient due to Machine Concept	Efficient Dust Extraction possible	

CONCLUSION -

ROBOTIC GRINDING – CONCEPT SELECTION AS KEY TO SOLUTION SUCCESS

Robotic auto grinding is a revolutionary technology in the ferrous casting industry. It leads to key benefits such as consistency in quality, high productivity, and health and safety on the shop floor. Solution selection is a key factor for the success of the project technically and economically in a foundry. Major parameters that affect this selection are –

Size and shape of Castings

Flash Levels
Product Mix
Load/Unload Automation

An Engineering study to establish suitability is recommended especially for castings in 10kg – 100kgs range for optimal solution.

Thank you

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