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Design of Reconfigurable Manufacturing System: A Review

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Abstract

This paper gives a brief introduction on Reconfigurable Manufacturing System with its design principles. It also discusses how reconfigurable manufacturing system is configured and proposes a method for calculating the number of possible rms configurations based on the number of machines in the system. A comparison between rms configuration and cell configuration is an important part of this paper. Here we have explained how to design rms with all six core characteristics and with the integration of innovative reconfigurable machine tools and reconfigurable inspection machines into the configuration. The six core characteristics are: Modularity, Integrability, customized flexibility, convertibility, scalability and diagnosability. These two principles make rms more productive and responsive. An accurate mathematical method is introduced for designing rms.

Key Words: *RMS Configuration, Cell Configuration, Reconfigurable Machine Tool, Reconfigurable Inspection Machine*

I. Introduction

Today's Manufacturing Industry faces challenges such as unpredictable demand, requirement of variety of products, rapid development in product and process technology, reducing lead time and increasing product quality. Although traditional manufacturing systems like Dedicated Manufacturing Lines (DMLs) are capable of producing similar products in high volume but incapable of giving product variety. On the other side, Flexible Manufacturing System is capable of giving product variety but as compared to DMLs its productivity is very low. Besides FMS is incapable of giving volume flexibility and also the cost is high. Reconfigurable Manufacturing System is a manufacturing System that possesses the advantages of both Dedicated Manufacturing Lines and Flexible Manufacturing System. Reconfigurable Manufacturing System has the capability to adjust both production capacity (parts produced/unit time) and functionality (part variety). RMS Systems are designed to cope with situations where both productivity and system responsiveness are of vital importance. RMS provides product flexibility but this flexibility is customized. That means each RMS system is designed to produce a particular family of parts. Also RMS is scalable i.e. manufacturing resource can be added and removed to change the production capacity. RMS is designed to react rapidly and cost effectively

- to market changes i.e. changes in product demand
- to product changes i.e. changes in product design
- system failures (ongoing production despite machine failure)

The main components of RMS for machining are CNC Machines, Reconfigurable Machine Tools and Reconfigurable Inspection Machines.

II. Classification of Configurations

The classification of configurations requires the determination of the number of possible configurations. The minimum number of machines, N needed in the system is calculated by the following equation.

$$N = \frac{Q \times t}{\frac{Min}{day}\, available \times Machine\ Reliability} \qquad (1)$$

Q = daily demand (parts/day)
t = total machining time for the part (min/part)
Maximum calculations assume 100% reliability i. e. machine reliability = 1.

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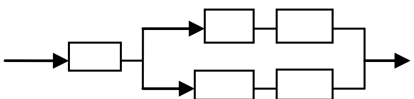
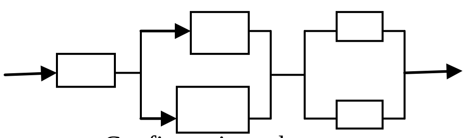
First, configurations are classified as symmetrical configuration and asymmetrical configuration. Symmetrical configuration is the configuration in which a symmetric axis can be drawn. Asymmetrical configuration is the configuration in which symmetric axis cannot be drawn. A configuration is then evaluated by its machine arrangement and connections. The type of material handling system determines the connections of a configuration.
For example, configurations **a** and **b** have identical machine arrangements (one in stage 1, two in stage 2and two in stage 3), but they differ because of different connections among the machines.

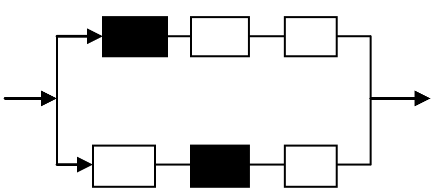


Configuration- a

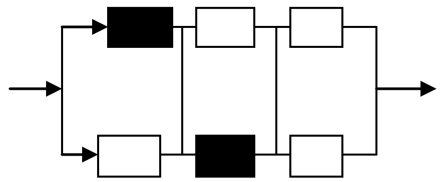


Configuration – b

Configuration b uses cross coupling between stages 2 and 3.
Symmetric configurations may be further divided into following three classes.
Class I – These are the configurations consisting of several serial manufacturing lines arranged in parallel with no crossovers and known as cell configurations.



The above figure shows symmetric configuration of class I. If the two black marked machines fail, the system production stops.
Class II – These are the configurations with crossover connections after every stage and known as RMS configurations. A part from any machine in stage (i) can be transferred to any machine in stage (i+1).



The above figure shows symmetric configuration of class II. If the two black marked machines fail, the system production may not be 100% but will not stop.
Class III – These configurations are the configurations in which there are some stages with no crossovers.
Asymmetric configurations are complex and study of asymmetric configurations is beyond this paper.

III. Comparison between RMS configuration and Cell configuration

The comparison between RMS and Cell configurations is based on the following four factors.
Capital Investment - Both the configurations have similar machine arrangements but different connections between the machines. The part handling system is simpler and smaller in cell configuration as compared to RMS configuration. Thus capital investment in RMS configuration is much higher.
Line Balancing - To be perfectly balanced, the processing time in all stages of the cell configuration must be exactly equal. But to achieve a balanced RMS configuration only the following relation needs to be satisfied

$$t_{s1}/N_{s1} = t_{s2}/N_{s2} = t_{si}/N_{si} \quad (2)$$

where N_{si} is the number of machines in stage i and t_{si} is the processing time per machine in stage i. Thus line balancing in RMS configuration is much better than cell configuration.
System scalability – RMS configurations are far more scalable than cell configurations.
Productivity – Though machine reliability is low due to crossovers at each stage, an RMS configuration offers higher productivity than that of a cell configuration.

IV. Calculation of No. of RMS configurations

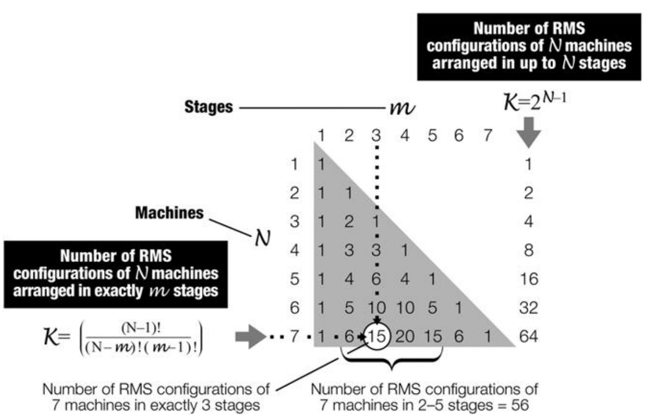
The authors of [1] have proposed a practical mathematical method that engineers can easily utilize for designing reconfigurable manufacturing systems. We have already seen that the minimum number of machines N required in the system can be easily calculated by solving Eq. (1). The basic equations for calculating the number of possible RMS configurations are given below. **K** the number of possible RMS configurations with **N** machines arranged in up to m stages is calculated by:

$$\mathbf{K} = \sum_{m=1}^{N} \binom{N-1}{m-1} = 2^{N-1} \qquad (3)$$

K, the number of possible configurations with **N** machines arranged in exactly **m** stages is calculated by:

$$\mathbf{K} = \left(\frac{(N-1)!}{(N-m)!(m-1)!}\right) \qquad (4)$$

For example, for **N** = 7 machines arranged in up to 7 stages, Eq. (3) yields **K** = 64 configurations, and if arranged in exactly 3 stages, Eq. (4) yields **K** = 15 RMS configurations. The mathematical results of these two equations for any **N** and **m** may be arranged in a triangular format, known as a Pascal triangle, shown in the following figure.



The numerical value of each cell in the Pascal triangle is calculated as follows. The numerical value corresponding to **N** machines arranged in **m** stages is calculated by:

The value for **N** machines in **m** stages = (the value of **N**-1 machines in **m**-1 stages) + (the value for **N**-1 machines in **m** stages).

For example, in Pascal triangle shown in figure, the cell of **N** = 6 and **m** = 3 shows 10, which is the sum of 4 + 6 of the previous line of **N**−1 = 5 machines with 2 and 3 stages.

The triangle also allows the designer to immediately visualize the number of possible RMS configurations for **N** machines arranged in **m** stages. For example, there are 15 RMS configurations when 7 machines are allowed to be arranged in exactly 3 stages. In addition, the Pascal triangle allows the designer to immediately calculate the number of possible RMS configurations for **N** machines arranged between *i* stages and *j* stages (*i*, *j* < **N**).

V. Conclusion

The new system should be designed at the outset for reconfiguration. This is achieved by designing the system and its machines for adjustable structure. The structure may be adjusted at the system level, at the machine level and at the control software. This adjustable structure facilitates system scalability in response to market demands and system/machine convertibility to new product. The manufacturing system should be designed around the part family with the customized flexibility required for producing all parts of this part family.

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