Multiscale Analysis of Reconfiguration for Reconfigurable Manufacturing Systems

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Abstract - Reconfigurable manufacturing systems (RMS) show multiscale characteristics on the granularity of reconfiguration. In order to assist manufacturing enterprises to appropriately select a reconstruction scale, the performance of manufacturing system was transformed into signal, which was disposed to be quantitatively expressed. On the basis of the characteristics and structure principles, the multiscale characteristics of RMS were proposed. Then a multiscale intrinsic model was established. Fourier transformation was used to reveal and quantitatively state the relationship between the reconfiguration scale and system performance. The model was then validated by means of a case-study.

Keywords - Fourier transform, multiscale, production performance, reconfigurable manufacturing system

I. INTRODUCTION

In the 21st Century, in the circumstance of increasing global competition, manufacturing enterprises are confronting with rapidly changes in market demands [1]. Traditional paradigms, such as dedicated manufacturing lines and flexible manufacturing systems become inadequate in meeting the market demands on capacity and functionality, giving rise to redundancies and deficiencies in productive resources. To keep competitiveness in such a global competitive environment, manufacturing enterprises should utilize new manufacturing paradigms, which are costly effective and can rapidly respond to requirements. In 1999, the concept of reconfigurable manufacturing systems (RMS) was firstly proposed systematically by Koren [2, 3]. Recent years, reconfigurable machines [4-6], reconfigurable manufacturing cells [7-9], and reconfigurable system [10-14] were widely researched.

In this paper, the multiscale characteristics of RMS were described and a multiscale intrinsic mathematical model was established. Daily capacity, that is able to reflect production efficiency, was chosen as the production performance signal, so that the analysis process is simplified. The production performance signal is mathematically transformed to arrive at the quantitative relationship between reconfiguration scales and performance changes. The purpose intends to assist decision-makers in scales-selecting for reconfiguration.

II. PRINCIPLES OF RECONFIGURATION

The construction of RMS includes equipment selection and distribution. Equipment selection is the procedure that matches the process design with the actual productive resources. Equipment distribution is the procedure that arranges the selected equipment, it’s designed based on the product task and process requirements etc. In RMSs, products are grouped into families, each of which requires a system configuration [15]. When products are in the same family, the whole line reconfiguration is not necessary but some adjustments in the line will be needed as the products change.

Producers are primarily concerned about functionality and capacity. Generally, the reconfiguration of reconfigurable manufacturing tools (RMT) is oriented towards functionality, while the reconfiguration of production cells is oriented towards capacity. Machining precision is a type of functionality, which, in turn, will influence on the efficiency of a product line. When RMTs fail as regards precision, procedures such as updating or replacing the function modules are required. To improve capacity, adding or removing machines to match the new throughput requirements and concurrently rebalancing the system for each configuration, should accomplish the system reconfiguration [16].

A. Criteria selection

The high degree of flexibility of RMS is in terms of its capacity and functionality. With regard to the sophistication of RMS, productive function is no longer a primary issue, as there are various configurations, which could be selected for manufacturing configurable machines, which tend to cater for corresponding to requirements of processing techniques. The design of RMS is driven by external demand, since the aim of RMS exogitation is sustaining productive capacity with minimal redundancy and the lowest deficiencies.

Furthermore, productive functionality could be conveyed by productivity capacity. On the assumption that a current configuration of RMS does not possess the capacity for forging a particular output, then the capacity of the RMS for producing such an end product should be considered as being nil. On this basis, productive efficiency could evince the effect of the reconstitution and profitability of an enterprise, which should be considered as a dominant factor for a company, as a norm for measuring the performance of RMS productivity.

In dedicated manufacturing lines, the daily output of manufacturing systems is fixed. Based on RMSs, daily
production changes, in response to external requirements. Regarding a RMS as an integrated item, without contemplating internal reconfiguration, the daily production could be treated as an index reflecting productive efficiency. Abiding by the criterion that, ‘to reconstruct what is inferior’, the effect of reconfiguration should be, ‘visible’ and demonstrated by daily productivity.

On the assumption that the operational use time of a manufacturing system per day is \( T \) and the number of workpieces produced during \( AT \) is \( n \), then, the daily productivity of the whole system during \( AT \) could be calculated as Eq. (1),

\[
N_i = \frac{nT}{AT}
\]  

(1)

According to economic theory, the external demand conforms approximately to the demand curve, which could be regarded as reflecting the lifecycle of the production. With external the needs augmenting, the productivity of RMS, cannot outweigh s the outward demand, thus, the consignment could not be completed in a specific time and as a result, reconfiguration of the system should be considered. On the assumption that the amount of orders in a day \( i \) is \( Q_{ij} \) and the requirement for delivering of the goods is before day \( j \), the quantity of production in day \( m \) could be reckoned as formula (2),

\[
R_m = \sum_{a \leq im \leq jm} Q_{ij}
\]  

(2)

As for RMS, the conceptual reconfiguration should achieve producing \( N_i \) at time \( i \) within the day \( m \), fluctuating at, \( R_m \) according to the daily demand.

B. Production performance signal

On the basis of ignoring intermittent issues (please check this carefully!) during the reconfiguration processing, the productive signal of manufacturing systems is incessantly changing, which could be regarded as a continuous-time signal. During the time domain, productivity could be considered as function \( v(t) \) to time \( t \), where the voltage of resistance is \( R \), therefore, the average power is:

\[
P = \lim_{a \to \infty} \frac{1}{2a} \int_a^t \frac{v^2(t)}{R} dt
\]  

(3)

When electrical resistance equals 1 ohm, the average power relates to the signal, as:

\[
P = \lim_{a \to \infty} \frac{1}{2a} \int_a^t v^2(t) dt
\]  

(4)

And the power of the signal is:

\[
E = \int_a^t v^2(t) dt
\]  

(5)

If a signal’s energy has limits, it is called an energy signal; if its power is limited, it is called a power signal. A cycle of production, which is consistently limited, is a time-signal, therefore, in a life cycle of an RMS, the mechanical system’s productivity signal is limited, which is a typical energy signal. If the ideal RMS is deemed to have ideal reusability and its life cycle is considered as being unlimited, then in ideal RMS life cycle, it has unlimited consistent time-signal. Obviously, Eq. (4) has its limit and the RMS has unlimited energy, with limited power. The result is that, the productivity signal in whole life cycle is a power signal.

III. MULTISCALE CHARACTERISTIC OF RMS

BASED ON PARTICLE SIZE

A. Intrinsic description

The form of RMS presents multiscale features regarding time-scale and space-scale, therefore, the definition of multiscale should be made initially, when it is to be considered. When considering changes in different scales after a system has been divided into different scale group, in a space-scale, based on different granularity, it is possible to divide it into a system level, unit level and machine-tool level (Fig.1). Granularity is similar to the concept of granularity and scale in a landscape pattern, with the smaller the granularity, the more detailed is the research (Fig.2). The object of research changes from considering the layout of the plant, to the reconfiguration of reconfigurable manufacturing tools (RMT) according, to the operation cluster of a single workpiece.

Generally speaking, scale is the magnitude of time and space but to define scale in RMS in this manner is inappropriate. In a mechanical system, clearly the size of machines differs and different work pieces also have numerically level difference. This paper will analyze the relationship between RMS of systems, producing units for systems and machines for production units.

RMS is similar to a level system and therefore, the scale involved inclines towards the definition of organization scale and function scale, in Hierarchy theory. At different levels, different sub-systems have different functions and have a clear position in the complete system. Although they are different from typical time-scales, they can be considered as comparable in certain ways.

![Fig.1. Characteristics of reconfiguration scale](image)

![Fig.2. Diagram of granularity and amplitude](image)