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FLEXIBILITY OF MANUFACTURING SYSTEMS

Summary. The flexibility of a manufacturing system is regarded as its ability to change easily the type of product or/and the size of production. The attempt has been made in the paper to establish a measure for such flexibility. The discussion is presented on the relation between assessment of flexibility and the size of production for which the manufacturing system has been designed. The difference between flexibility and adaptability of manufacturing systems is underlined.

1. What is flexibility?

The adjective "flexible" has been recently used quite frequently in the field of manufacturing production, especially as part of the very popular term Flexible Manufacturing System, FMS. In the field of manufacturing the meaning of "flexible" seems to be close enough to the meaning of the word in the everyday life and may be translated as "easy to change". Nobody understands it as in Mechanics when the adjective flexible is used with the reference to the compliance of mechanical structures. That is rather clear - but the exact meaning of the word and the measure of flexibility is not clear.

A change in manufacturing production may have different meanings and is not easy to define - it will be discussed in the following chapters of the paper. At this stage let us assume that the adjective flexible is used for comparative qualification purposes of two systems which are performing the same manufacturing task W_1 and should change their activity to task W_2. It takes time and money. The system in which the change will need less time or/and money is assumed to be more flexible. How to compare flexibility if the change needs less time T but more money M? In free market economy a span of time may be usually treated as a certain amount of money and flexibility F may be then expressed as:

$$F = \frac{1}{kT + M}$$

and measured in the inverse units of money. The coefficient of recalculation k, however, changes from one case to another because it depends on the situation - depends on how much "the customer" is ready, in this particular business situation, to pay for the shortening of the waiting time. The coefficient k may be treated as the price of time. For the assessment of the system flexibility an average price of time has to be used but that average value is difficult to be evaluated.

To describe a manufacturing task many variables should be used. For convenience of presentation let us suppose that there are only three such variables and that the specific task may be represented by the point in the three-dimensional space X, Y, Z, as in Fig.1. In the specific manufacturing system there may be several possibilities of the change from task W_1 to task W_2 - they are presented in the figure by two different paths a and b, each one associated with the different values of T and M. For the assessment of flexibility of the system the path which gives the biggest value of F, calculated from the equation (1), should be taken.

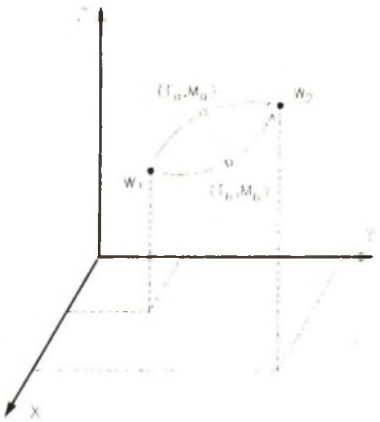

Fig. 1. Change of manufacturing task W_1 to task W_2

2. Flexibility of what?

It is difficult to find a precise definition of the term Flexible Manufacturing System but everybody "knows what it means". In this fuzzy but generally agreed meaning FMS is usually understood as a group of machine tools and auxiliary equipment, computer controlled, with automatic transport of tools and workpieces, designated for **machining** a family of parts. Sometimes it may be a group of robots and auxiliary equipment designated for **the assembly** of the family of products.

Machining or assembly is, of course, only part of manufacturing. For many years there was a long and extensive discussion in the CIRP STC "Optimization", led by E.Merchant, on English-language definitions and nomenclature for manufacturing systems. The definitions were formulated and published four years ago [1]. Some of the definitions are quoted below and numbered for easier reference.

[D1] 'Manufacturing is a series of interrelated activities and operations involving the design, material selection, planning, production, quality assurance, management and marketing of the products of the manufacturing industries.'

[D2] 'A Manufacturing System is an organization in the manufacturing industry for the creation of manufacturing production, or, simply, production. In the mechanical and electrical engineering industries, a manufacturing system, in general, has an integrated group of functions: e.g. the sales, design, production and shipping functions...'

A manufacturing system, as defined above, is involved in much more than just machining of workpieces. Certainly from the market point of view flexibility of the whole system of this kind is important. According to the common interpretation of the acronyms it is rather CIM attitude than FMS. In the CIRP document there is no definition of a flexible manufacturing system, FMS. The term an automated manufacturing production system is defined and its flexible version is close to what is commonly understood as FMS.

[D3] 'An Automated Manufacturing Production System is a unit within a manufacturing system consisting of an integrated assembly of the machines and/or associated equipment necessary for the carrying out of manufacturing production with the minimum of manual attention, together with the means for transferring components automatically through the system, all operating under full programmable control. In engineering manufacture an automated manufacturing production system will usually include machine tools for machining or forming materials but may contain also other machines for, e.g. washing or for assembly of products and/or other equipment, e.g. for painting and may also include computer-aided scheduling, planning etc. capabilities.'

The dedicated and flexible systems are distinguished.

[D4] 'A Flexible Manufacturing Production System (FMPS) is an automated manufacturing production system which is capable, with the minimum of manual intervention, of producing any of a range of family of products. The flexibility will usually be restricted to the family of products for which the system was designated.'

The paper deals with such systems but, because we are all accustomed to the acronym FMS that acronym will be used and not FMPS. It is worth noting that in the definition D4 flexibility of a system has been connected with 'the minimum of manual intervention'. It is, however, the feature of automation not flexibility.

Manufacturing production involves different processes. Machining is the most important of them and in the following chapters flexibility will be discussed on the examples of machining systems.

3. Main parameters of machining systems

There are many parameters which should be used to describe fully a machining system. The most important ones seem to be: the size of production and the variety of parts which can be machined. From the point of view of these parameters the system may be more or less universal. Universality and flexibility are connected somehow one with another. When we use adjective flexible we think not only how easy it is to make a change but also about a possible "size" of the change.

3.1.Size of production

Valckenaers analyzing carefully flexibility of computer controlled production wrote [2], what is commonly agreed on, that FMS attitude has its "niche" in the medium size production. It has its place somewhere in between one off production, where man-operated machines are the best solution, and transfer lines as typical dedicated automatic machining systems for mass production.

Looking from the flexibility point of view there should be considered both: the economically justified range of production size of the system and how easy it is to change the size of production. Expectations according to the range of economically justified production size and how easy it should be to change it are much bigger in the cases of small-lot than mass production systems. It is illustrated in Fig.2 where the size of production P is shown along the vertical axis. Both: FMS1 and FMS2 are flexible systems in spite of differences in the ranges of economically justified production sizes.

3.2.Variety of products

Flexibility is seen, first of all, as a possibility of machining a variety of workpieces - a bigger or smaller family of workpieces. Again, looking from the flexibility point of view, both are important: the size of the family and how easy it is to change from machining of one type of workpieces to another. In the case of system designated for small-lot production there is expectation of much bigger family of parts to be machined than in the case of dedicated machining system - see Fig.2 where variety of parts V is shown along the horizontal axis. The system should be also used with justified costs for relatively big range of production sizes.

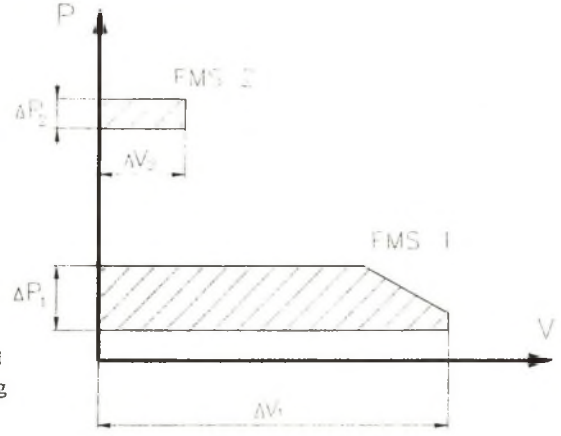

Fig.2. Varieties of products (workpieces) and production sizes of two manufacturing systems (machining cells)

It is possible to draw a conclusion from the above considerations that the assessment of flexibility depends very heavily on the size of production for which the machining system has been designed. With the same amount of time and effort needed for the change from the manufacturing task W_1 to task W_2 a system designed for mass production will be treated as very flexible one and a system designed for batch production as a rigid one.

4. Flexibility from the point of view of disturbances

Any change of the size of production or the type of products is a disturbance for the manufacturing system, but it is a special kind of disturbance. It is a disturbance which enters the system through a known input, the input which is under control. The information about this kind of disturbances may be known before it affects the machining system.

The "classical" disturbances enter the system from environment or appear inside the system and are stochastic by their nature. For example it may be: an increase in temperature in the workshop, the material of workpieces harder than expected, a failure of the tool... Some people expand the meaning of the word flexible and describe a manufacturing system as flexible when it can cope with such disturbances. It is not justified - quite different features of the system are needed for this purpose.

The machining (or manufacturing) system which is able to deal with stochastic disturbances should be rather described as fail-safe and adaptable. Safety is connected with a catastrophic failure of the system which may require an emergency stop and a recovery procedure afterwards. Adaptability is connected with quality of products or quality of manufacturing processes and require automatic adjustments of process parameters. Both safety and adaptability may be inherent, natural features of the system or they may be introduced into it by a supervisory system [3].

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