6th International DAAAM Baltic Conference
INDUSTRIAL ENGINEERING
24-26 April 2008, Tallinn, Estonia

ENHANCING FLEXIBILITY IN IRON FOUNDRY

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Abstract: *The requirements set for iron casting SME jobbing foundries, due to the changes in customer requirements and business environment, are presented. Typical jobbing foundry is analysed. Requirements for the flexibility and agility of the foundry production process are considered. Means for enhancing flexibility in an iron foundry to meet these requirements are also briefly discussed. A concept of an ultra-agile iron foundry is described.*
Key words: iron foundry, flexibility, agility, service concept, production control

1. INTRODUCTION

1.1 Background

Currently European foundries are fully booked. Yet, there are serious challenges affecting profitability, customer service performance and future in general. Delivery times are long and delivery reliability is unsatisfactory. Shortage of skilled workforce is already a major problem. Retirement is causing further challenges, especially for retaining the so called silent knowledge. The business environment has changed, global competition has tightened, raw material and energy prices have risen and general uncertainty has increased.

Customer requirements have also changed. Customers want fewer suppliers to supply larger systems and are increasingly out-sourcing production to subcontractors [1]. Based on conducted interviews with casting users in Finland [2], casting users expect foundries to offer globally competitive total price level, high delivery reliability, flexibility and ability to deliver wider range of castings at a short notice accompanied with customer service and cast component design support. While the emphasis is still on the price, the importance of non-cost related factors is increasing [3]. Castings users want to buy ready-to-install components or sub-assemblies instead of raw castings [2].

Most SME (small and medium size enterprise) foundries have not invested in customer service and product know-how or paid much attention to long-term competitiveness. This attitude might work during the current "seller’s market" situation, but not when the demand for castings starts to stagnate.

In general, there are two possible means to enhance the basic profitability of a foundry business: limiting supply or increasing demand. For long-term profitable operation of European SME jobbing foundries, increasing demand cannot be based merely on offering lower prices. A more sustainable approach for iron casting SME's has been proposed [4]: increasing demand by serving wider range of customers and by providing wider range of castings with full customer service. Such service can be delivered by combining local homebase foundry production with exploitation of the benefits of far-off outsourcing from low-cost countries. The homebase foundry should be able to deliver also short series and prototype castings and ensure fast first deliveries and high delivery performance accompanied with full customer service [4].

1.2 Aim and scope of the study

The connection between the service concept, service performance and the subsequent requirements for the production process and methods applied is discussed. A concept of an ultra flexible and agile iron casting SME jobbing foundry is described. Such a foundry would be able to profitably provide wide range of iron castings (in terms of series size, product type, and cast iron type and alloy) to scattered customer segments with short delivery times and high delivery reliability. Various requirements set for the agility and flexibility of foundry process and subprocesses are discussed.

2. LITERATURE REVIEW: FLEXIBILITY AND AGILITY

Often terms 'flexibility' and 'agility' are used in the same manner. Flexibility has been defined as "the ability to change or react with little penalty in time, effort, cost or performance" [5]. Agility has been defined as "the ability to rapidly alter any aspect of the manufacturing enterprise in response to changing market demands [6].

Flexibility is a multi-dimensional construct and there are several types of flexibility. Competitive environment should determine the type of flexibility a firm should emphasize [7]. According to [8] and [9], flexibility to respond correctly to changes in the competitive environment is imperative to remain competitive in the global marketplace. Flexibility can be seen both as internal ("capability") or external ("competitive edge") [5].

Several researchers have developed concepts of flexibility. Gerwin's [10] taxonomy of manufacturing flexibility include following dimensions: volume, materials, mix, modification, changeover and rerouting flexibility and flexibility responsiveness. Two aspects of flexibility are included: range and temporal. Upton [5] has presented following 15 categories of manufacturing flexibility: routing, product, mix, action, state, volume, program, long-term, short-term, expansion, machine, labour, design-change, operation and process flexibility. Koste and Malhotra [11] have identified ten dimensions and four elements of flexibility. The flexibility dimensions include machine, labour, material handling, routing, operation, expansion, volume, mix, new product and modification flexibility. The elements of flexibility include range (number and heterogeneity), mobility and uniformity. Range-number captures the number of achievable options and range-heterogeneity captures the differences between options. Mobility refers to the ease with which the organisation moves from one state to another. Uniformity refers to the similarity of performance outcomes.

D'Souza and Williams [8] have proposed following manufacturing flexibility dimensions: volume and variety flexibility (externally-driven dimensions) as well as process and materials handling flexibility (internally-driven dimensions). Each dimension has two elements: range and mobility. Range defines the extent of flexibility on each dimension. Mobility represents the firm's agility in making the changes on each dimension. Duclos et al [12] have proposed a conceptual model of supply chain flexibility with six flexibility components: operations system, market, logistics, supply, information systems and organizational flexibility.

Interestingly, Upton [7] found that investment in computer-integrated manufacturing (CIM) reduced product range and the degree of computer integration was not associated with either increased range or improved changeover times. Thus investments in CIM resulted in decrease in flexibility. Additionally Upton [7] concluded that much of the variance in plant flexibility could be explained rather by managerial action than by the structural characteristics of the plant.

3. ANALYSIS OF SME JOBBING FOUNDRY

In Finland, most independent iron foundry companies are SME subcontractors with a single production plant. They have numerous customers with various needs. SME foundries typically utilize manual or semi-mechanised moulding methods. Automatic moulding/pouring lines are rare in independent SME's, but more common in non-independent foundries of foundry groups. In case of manual moulding, flaskless moulds and different sized wooden flasks are typically used.

In the melt shop, a limited number of relatively quick and small capacity induction furnaces are used. In most cases there are no holding furnaces. Manual moulding foundries also often buffer moulds, and even pour the melt in them, on the shop floor. Thus, typical SME foundry production capacity apparently exhibits inherent flexibility. In reality, SME foundries tend to be only effective in providing relatively narrow spectrum of product types, iron grades and series sizes. In the production, single and short series castings, uncommon alloys and rare product types are considered rather as technical and economical problems. Flexibility of a SME foundry is analysed in the Table 1.

The batch melting practice and the production control systems tightly connected to it, suit best for running relatively large series or volumes. Moulds and pouring operation are most of the time waiting for the next batch of melt. Thus, the foundry process is actually pulse timed according to the "natural bottleneck", the delivery of each melt batch. Increasing the melting capacity, as such, will increase the total production, but may have no effect on the real flexibility and agility.

Sourcing of patterns and coreboxes is often the most serious challenge to the agility of the iron foundry process. Supplying a pattern takes typically several weeks. This affects especially the ability to provide prototype, test, single and short series castings.

SME foundries represent mixtures of advanced and traditional production methods and systems. Various ICT tools and modern technologies, regarding 3D-based CAD/CAM, pattern making and casting simulation as well as tools for quality engineering and production management etc., are utilized. However, in almost all cases, decisions over the production capacity and methods seem to base on practical, short term economic priorities, instead of long term business decisions about customer service, delivery performance and agility. A systematic and integrated approach in developing a "digital production environment" and integrating flexible systems and high delivery performance into it seems to be completely missing.

The effective processing time of a casting; consisting of moulding and core making, assembling moulds, pouring, cooling, fettling, cleaning etc.; often constitutes small part of the typical delivery time. Apparently, it seems that it may be difficult to significantly speed up deliveries merely by enhancing performance of individual subprocesses within the foundry plant. If the production system is not tuned to mould-by-mould production, there is little flexibility to be applied in the service concept.

As a general result, the SME service practice is inherently prone to be shifting towards selectivity and narrowing customer base and series size, material and product spectrum. On the other hand, competition from the less labour intensive and more economic mass producing automatic line foundries makes it difficult for most SME's to compete in the longer series markets.

4. REQUIREMENTS AND DEVELOPMENT NEEDS FOR SME JOBBING FOUNDRIES

In order to succeed and survive the inevitable changes in the European iron castings market, ultimate challenges for the SME iron foundry can be summarized as:

- Finding workforce or constructing less labour intensive production capacity.

- Applying a wider service concept; delivering wider spectrum of products, design cooperation and technical support, i.e. being the easiest mean of sourcing cast components and sub-assemblies.
- Increasing flexibility; Gaining ability to serve wider customer and product base including single casting, test, short and longer series castings with different product types, sizes and iron materials.
- Increasing agility; Gaining agile production enables superior response and delivery performance.

Environmental regulation will also have a greater impact on the profitability of a foundry in the future. Due to high raw material and energy costs, optimal control of alloy and impurity levels and use of energy have to be tightly controlled by an active production optimization system.

Table 1. Characteristics of flexibility in a SME foundry

Flexibility dimension	General definition	Analysis and examples of occurrence in foundries
Machine	The number and variety of operations a machine can execute [11]	Typical machine in a foundry can execute only one simple operation.
Routing	The ability to change the sequence of steps in the production process [10]	The sequence of the steps in the production processes of an individual casting cannot be changed, only some post-cast operations. Buffering practice can be variated. The routes within the subprocesses can be minutely changed.
Volume	The ability to change the level of output of a manufacturing process [8]	Without investments, the volume of production can be increased merely by adding working hours (number of shifts).
Mix -series sizes -material grades -product types -component sizes	The number and variety of products which can be produced [11]	Inflexibility in the process leads to selectivity in taking orders. Especially automatic moulding line foundries are seen as inflexible, long series production units. Thus prototypes and short series are not wanted. The ranges of sizes and series sizes cast in a foundry are limited. Cast product types may vary. Different grades can be produced but not flexibly. There is inherent tendency to not change composition frequently and especially just for single or short series.
Modification	The ability of the system to incorporate design changes into a specific product [10]	Patterns need to be modified or replaced each time. Ramp-up time; it takes several weeks to produce new casting.
Information systems	The ability to align information system as it responds to changing demand [12]	Production control bases on setting predetermined schedules and capacity is booked far ahead. Sudden changes (material grade, new urgent proto etc.) cause problems. Sellers are generally not well enough integrated with the momentary capacity status information.
Materials flexibility	The ability of the manufacturing system to accommodate uncontrollable variations in the materials and parts being processed [10]	Systems for raw material use and the batch melting technique are not efficient in using the raw materials available (with varying impurity levels, e.g. Zn containing scrap). Variations in the composition of the scrap and the melt result in quality problems and inefficient raw material use.
Process	The ability of the system to adjust to changes/ disruptions in the manufacturing process (machine breakdowns, changes in the production schedules etc.) [8]	Melting and moulding most are vulnerable subprocesses. In case of machine breakdown in moulding or melting, production is halted, if the used machine has no substitute. Usually two induction furnaces are exploited. Breakdown or lining repair decreases capacity. Use of single pattern sets without substitutes constitutes risks. Pattern making is a vulnerable bottleneck and source of many delivery delays.

4.1 The concept of an ultra-flexible iron foundry

Technical and production decisions related to the concept of an ultra-flexible iron foundry are dictated by the full service concept and exacting requirements for flexibility, agility and delivery performance. Instead of focusing on limited sectors of "good orders", customer and product base as wide as possible is sought for. Single and short series castings are to be delivered along with long series.

As “a printer”, an ultra-flexible foundry would exhibit the ability to produce any type of casting, ultimately "mould-by-mould", amongst any kind of schedule of other casting production. Thus, any order or any single casting must be able to be put into production at any moment.

This approach results in complete re-organising of the foundry production process and control. Single component casting, mould-by-mould, would rather be a standard than an unwanted order.

4.2 Production subsystems in an ultra-flexible foundry

Following the requirements set by the stringent full service concept, the most radical development needs are subjected to melting and moulding and production control system. Process robustness should be increased by moving from narrow linear production systems towards parallel systems within each subsystem.

Due to the requirements for agility and robustness, mould and core making has to exhibit overcapacity and utilize several parallel moulding lines, which can be operated interchangeably. Along with conventional moulding, patternless moulding method has to be applied. Moulding has to utilize modular flexible flask system along with flaskless moulding capacity. For the flexibility demand, a pool of moulds must be able to be buffered and then sent to pouring at any instance. To minimize the setup times in moulding, a quick and effective pattern handling system is compulsory.

Melting shop has to be able to deliver any amount of any iron grade at a short notice. This is not a feasible requirement for typical batch melting process. Indeed, an almost inverse solution is needed. Selected raw materials are continuously fed into various small capacity pre-melt furnaces. Then the melts are poured in controlled proportions into induction ladle type furnaces, acting as mixing and treatment ladles. A selection of different capacity induction ladle furnaces gives the flexibility required when different alloys have to be delivered in varying volumes. Control of the process should be automatically run, basing on momentary status data of melts in furnaces, the raw material buffers and on the priority and casting data of the moulds in the buffer pool.

These agile moulding and melting systems are imperative. They are required to enable the degree of control freedom for each other and especially for the automatic production control system. This way the control system can optimize the flexibility and economy of the melting process and use of raw materials and energy as well as the delivery of the tasks.

The automatic production control system will be based on constantly changing optimization scenario. Conventional (order-by-order or batch-by-batch) scheduling is substituted with automated dynamic (casting-by-casting) control of the process. The tasks (moulds or castings) are not passing production stages according to any fixed schedule. Due to the high number of dynamic variables in the production optimization calculation, conventional optimization methods are substituted with an optimization solution based on random sampling.

5. CONCLUSIONS

Real change in the flexibility and agility and the service performance of a SME iron foundry requires considerable changes in the physical foundry production processes, in the general service concept decisions and in production control. Fulfilling the full service concept requires drastic enhancement of the agility and flexibility, which in turn means transformation from the conventional (batch-by-batch) foundry process into an ultra agile (mould-by-mould) process.

6. ACKNOWLEDGEMENTS

We thank Academy of Finland (project FC-ICT) for enabling us to carry out this work.

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