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Disruptive Technology as a Driver for the Sustainability of Traditional Manufacturing Supply Chains

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Abstract

The reconfiguration of manufacturing supply chains may be a desirable business objective for reasons of efficiency, cost and quality, amongst other things. However, the introduction of disruptive technology which in itself provides intrinsic manufacturing benefits may, as a consequence, necessitate that traditional organisations need to adopt new practices to accommodate the introduction of such novel processes. This paper examines how the activity of introducing breakthrough innovation must consider the wider impact beyond process technology and its implications for traditional manufacturing organisations.

Keywords: supply chain; disruptive technology; digitalisation; distributed manufacturing; breakthrough innovation

1. Introduction

Primetals Technologies is a leader in the field of engineering design for steel and aluminium metallurgical process plant, including plate, coil, strip and foil mills. In recent years the success of this business has been largely based on strong growth in China where crude steel production capacity has increased from 400mt in 2005 to 831mt in 2017. Although China's steel industry is expected to maintain a reasonably strong growth rate, c.a. 3.0% in 2017, (World Steel Association, 2018) for the immediate future, in the longer term it is unclear where sustainable growth for large capital equipment will come from. With urbanisation, which drives steel consumption, in developing countries rapidly approaching western levels it is feasible that we are seeing the early stages of saturation in global steel consumption.

At the same time, activity on near net shape, resource efficient and sustainable manufacturing continues to grow as a response to materials scarcity, emissions targets in production and energy efficiency in end-use applications. It is anticipated that customers will increasingly require Primetals Technologies to demonstrate technical expertise and a good understanding of the market applications for these technologies and it is the objective of its New Technologies group to evaluate, specify and ultimately commercialise such techniques. The industrialisation process for one such new technology, that of mandrel-free metal spinning, is now described with reference to its impact on existing supply chains and future potential to create new opportunities in well-established manufacturing sectors such as the automotive industry.

2. Die-less sheet metal forming technology

Increasing consumer and legislative pressures in many manufacturing sectors, demand greater levels of responsiveness and responsibility from OEMs and their supply chain partners for research and product development. Flexible manufacturing, as exemplified by die-less forming and specifically mandrel-free spinning, provides a clear challenge to the conventional prototyping and manufacturing regime that has the potential to reduce development cycles and correspondingly shorten time-to-market for new products.

This change in manufacturing strategy can be exploited by all members of the supply chain. For example, whilst OEMs aim to enhance their established position within the automotive industry, it is an opportunity for others in the value chain to grow volume and capacity to support the market created by the vehicle manufacturer. Competition in the automotive industry occurs substantially between competing supply chains. Those with efficient supply structures that rapidly reconfigure to changing demand will ultimately succeed against inflexible, asset intensive ones. Whilst much has been made of the new F-150 truck in the US, Ford estimates that the cost of re-tooling from steel to aluminium will be ca. $350m for the Dearborn plant. As a die-less forming technology, mandrel-free spinning provides a key shift in manufacturing philosophy to minimise or eliminate expensive tooling from press shops.

2.1. Dieless forming

As indicated above, the cost of stamping dies and spinning mandrels, as dedicated tools, is a major consideration and potential barrier when seeking to implement design change and select appropriate manufacturing technology. In response to this challenge the field of die-less forming has evolved with several attempts to limit or eliminate entirely the need for solid tools. Among the most widely studied is incremental sheet forming, (Emmens et al, 2010) in which sheet metal is formed by the indentation of a round-tipped stylus moving across its surface. The stylus follows the contour of a pre-determined target part and is highly amenable to CNC control. A wide range of parts can be fabricated in this way with no recourse to dies. However, the unavoidable accumulation of residual stress in the sheet metal part means that accuracy is compromised when compared with conventional stamping and deep drawing operations. A further adaptation of the process is double-sided incremental forming (Meier et al, 2011) which uses two strategically aligned stylus-type tools that follow pre-described toolpaths. The two tools, one on each side of the blank, can form a part with both concave and convex shapes incorporating highly-detailed features.

Other attempts to surmount the problem of tooling related costs include the use of multi-point, reconfigurable dies (Li, 2008) in which the working surface of the die is made up of individual active punches, called pins. In general each pin has a square cross section, a hemispherical end and can be independently moved in a vertical direction. The challenge for this technology is to determine a suitable medium which accurately transfers the profile of the pin bed to the sheet metal without leaving impression marks on the surface of the component.

2.2. Conventional metal spinning

Conventional metal spinning involves the forming of axisymmetric components over a rotating mandrel using rigid tools or rollers, Figure 1. The process uses a circular metal blank of thickness t_0 which is formed in a series of incremental passes against a solid tool or mandrel. No deliberate thinning is involved and the thickness of the final part, t_1 is nominally equal to that of the original blank. The process is very versatile and input materials typically include steel and a wide range of non-ferrous materials, aluminium and copper being common among them. However, the wider adoption of the process is limited by the need to manufacture a dedicated mandrel for every new part.

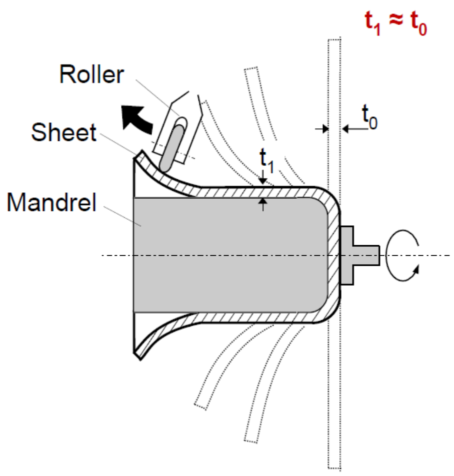

Figure 1 Conventional metal spinning

2.3.Mandrel-free spinning

A new, dieless metal forming technology has been developed in the Engineering Department at the University of Cambridge (Music and Allwood, 2011) and an up-scaled industrial prototype has been built by Primetals Technologies in the UK. The technology, based on the traditional and enduring process of metal spinning, removes the need for solid tooling by replacing the mandrel in the forming process with numerically controlled rollers, Figure 2.

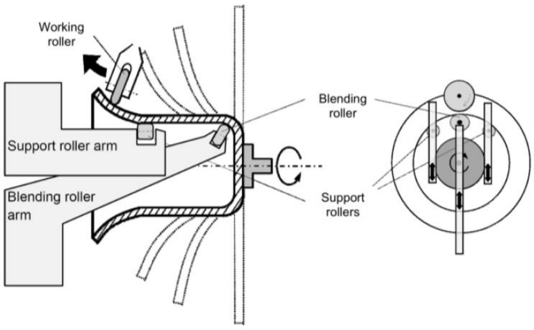

Figure 2 Mandrel-free metal spinning

The process therefore, has inherent flexibility and responsiveness to part geometry even to the extent that asymmetric part production is possible. Moreover, the accompanying reduction in cost makes the process attractive for small batch numbers, one-offs and prototypes. A summary of the technological features of the process and the benefits they enable for customers is provided in Table 1.

Table 1 Features and Benefits of Mandrel-free Spinning Technology

Machine Features	**Customer Benefits**
Die-less (mandrel-free)	Minimal tooling costs and set-up times
Computer based toolpath generation	Rapid changeover between parts
	Compensation for springback
Mandrel replaced with three support rollers	Complex geometries with re-entrant curvature
	Control of product wall thickness
NC rollers with closed-loop control	Improved tolerance and reduced rectification costs
Asymmetric shape control	Compensation for material anisotropy

3. Market structure and the traditional supply chain

The market for spun metal components is highly fragmented with many metal spinning companies operating diversified manufacturing facilities including pressing, polishing, machining, welding and general fabrication. In addition, end-use markets are diverse and may include engineering, automotive, aerospace, kitchenware and architectural applications amongst others. Despite its relatively unknown status as a manufacturing technology, it is this great diversity of market application that is one of its key strengths. Indeed, the German government recently blocked the sale of machine tool manufacturer Leifeld Metal Spinning to a Chinese company Yantai Taihai Corp., (Chazan, 2018). Leifeld specialises in high-strength materials used in aerospace and the nuclear industry

Whilst it seems is unlikely that a comprehensive and consolidated view of the end-use market is available, it may reasonably be assumed that there is some degree of commonality within the industry and that a number of generic component types exist. Moreover, irrespective of component or end-market, the approach to manufacturing by metal spinning companies is relatively standardised, involving the intermediate manufacture of a physical mandrel (either in-house of subcontracted), specific to the order requirement, the cost of which is amortised across the production run, Figure 3.

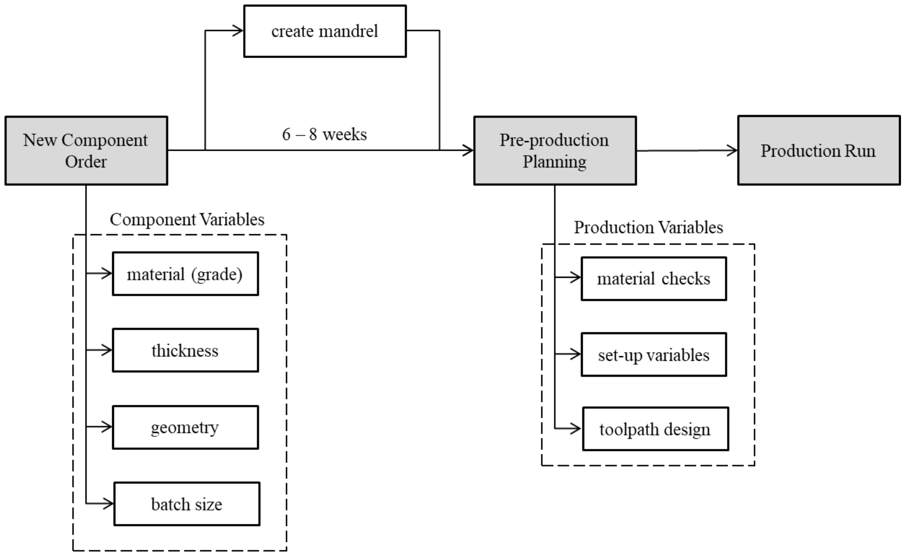

Figure 3 Order fulfilment in conventional metal spinning

Further, the production of this mandrel may take a significant period of time (6 - 8 weeks is not uncommon) thereby comprising an appreciable element of the manufacturing lead time. Competitiveness in conventional metal spinning may, therefore, be ascribed to some degree in terms of the cost and speed of mandrel production.

4. Digitisation and implications for the organisation

The successful development of a new engineering system brings together explicit knowledge of the input parameters to achieve an understanding of the outputs. The system that defines the mandrel-free spinning processes is described in the diagram below, Figure 4.

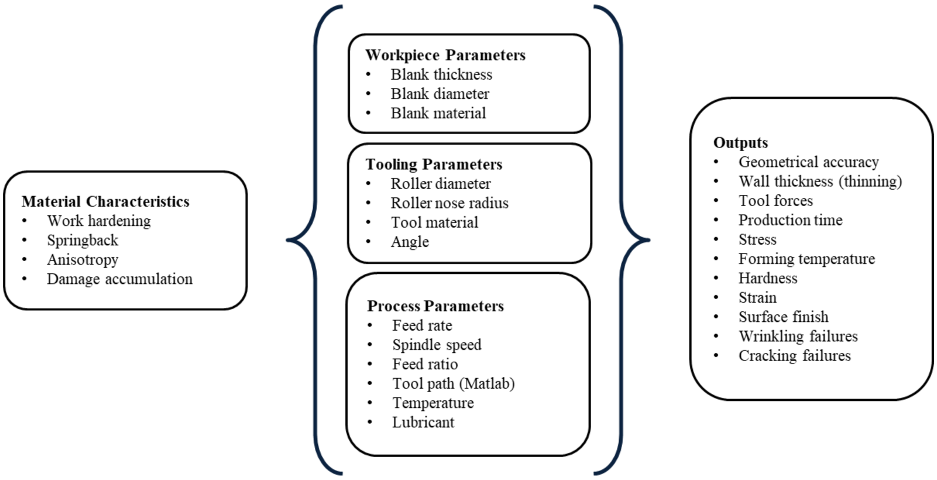

Figure 4 Spinning variables captured in the digitised environment, adapted from Wang (2012)

Achieving the full commercial value of mandrel-free spinning will be critically dependent on its successful realisation as a 'mechatronic package', e.g. a novel mechanical solution with complex automation. The basic mechanical layout of a mandrel-free spinning machine is determined by the size and geometric complexity of the anticipated product mix. Material and component combinations will determine the loads and forces experienced by the actuators and position control systems are evaluated in relation to their cost versus the response time and robustness of the actuators.

Development of the corresponding automation system is split into three parts;

a) Level 2 automation (initially off-line models) to calculate the tool path based on failure mode criteria, e.g. avoidance of cracking, wrinkling etc.

b) Level 1 automation to control the actuators to the set points.

c) Feedback system, such as cameras or lasers, to measure product tolerance with respect to reference product parameters (shape and thickness) and dynamically adapt tool path based on continuous monitoring of geometry.

Of the potential benefits offered by this new technology, most obvious is a compression in lead time owing to the elimination of the requirement to manufacture an intermediate mandrel; the technology of mandrel-free spinning creates the ability to move from 'CAD to part' in a predominantly digital environment. Whilst CNC control is normal in the machining industry and indeed increasingly commonplace in conventional metal spinning, the creation of a 'virtual' target shape as opposed to a physical one, is a significant inventive step and enabler toward enhanced supply chain competitiveness for this traditional process. Moreover, the digital environment is less reliant on traditional 'artisan' skills, which are increasingly difficult to find, and may indeed provide a platform for distributed manufacturing and the benefits of spatially variable costs, such as labour, by using codified toolpath algorithms. Further, such 'digitalisation' requires a new level of dialogue between customer and supplier (producer) where a key element of process ownership is displaced form the former toolmaker, Figure 5.

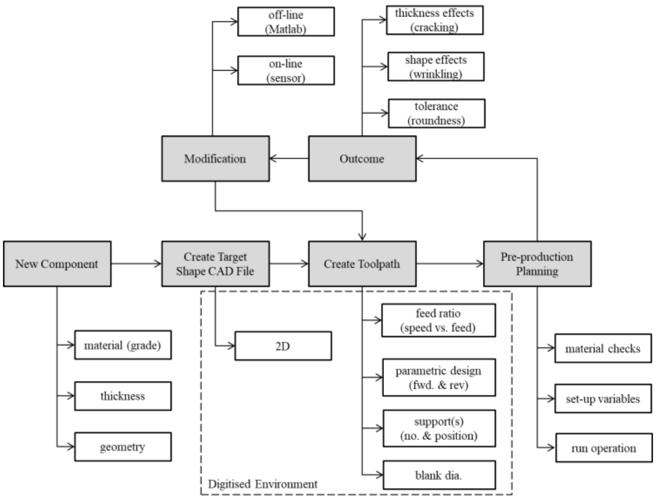

Figure 5 Order fulfilment in mandrel-free spinning

The introduction of disruptive technology and the accompanying re-engineering of the business process create an immediate and formidable challenge for the host organisation. The process of manual or hand spinning involves the acquisition of tacit knowledge, probably over many years. The transition to the digitised environment will most likely require the acquisition of new skills; designing in the virtual environment will necessitate 2D CAD and CNC machine programming knowledge, whereas design for asymmetric spinning will require a 3D capability (Loukaides and Russo, 2017) and the organisation must plan to deliver these skills. However, once familiarity has been established and the digitised process embedded, new opportunities may be generated through the application of techniques such as machine learning to optimise production methods. Thus the introduction of new technology mitigates not only in favour the organisation’s sustainability but also its longer term evolution and development.

5. Supply chain opportunities and the industrial ecosystem

The implementation of mandrel-free spinning facilitates immediate and sustainable advantages for any individual manufacturing entity. However, for a multi-site organisation the opportunity for cost-effective distributed manufacturing becomes more attainable without reliance on low labour cost economies. With part design and manufacturing instruction being entirely committed to digital structures, manufacturing can then be co-located with markets or customer facilities if desired. Further compression of the total value chain may then be realised since part design, manufacture and distribution then occupy a minimal geospatial footprint. Furthermore, it is also possible to locate manufacturing facilities according to the availability of necessary resources, skills or regions where favourable business environments may exist.

An example is now given of how mandrel-free spinning may be deployed in the automotive industry for the manufacture of exterior closures.

5.1. Application in the automotive sector

The automotive industry traditionally follows a consolidation strategy (e.g. generic platforms) to deliver economies of scale. However, car buyers globally are increasingly seeking performance and styling, alongside an element of uniqueness. Such mass customisation is an opportunity for vehicle OEMs to create and fill new niches by offering region-specific features that respond to the individual taste and expectations of the market. As a consequence, it will not be uncommon for automotive OEMs to have 20 or more vehicle “derivatives”. Such market segmentation demands shorter lead times and lower investment costs to reduce time to market and improve return on investment. Complexity and the pressures of cost are hence inalienable features of the supply chain that manufacturing companies must respond to. Innovation, therefore, requires new capacities and skills for suppliers in all areas; prototyping, testing and in the manufacturing process itself.

FELDSPAR (flexible die-less panel) is a UK-based collaborative industrial R&D project supported by Innovate UK, (now part of UK Research and Innovation). The five-member consortium, led by Nissan Motors UK is seeking to develop the immature technology of mandrel-free spinning and deploy it in automotive body panel manufacture. In 2016 industrial consortium partner, Primetals Technologies built and commissioned an up-scaled version of the laboratory demonstrator developed in Cambridge. With a capacity to spin a metal blank with a diameter of over 2 metres, this machine is uniquely placed to act as a test bed for prototyping die-less forming technology on an industrially relevant scale. The machine is currently located at The Manufacturing Technology Centre, a member of the High Value Manufacturing Catapult and partner in the FELDSPAR consortium. Importantly, the FELDSPAR consortium also includes Chasetead Ltd who provide prototype engineering and low volume production sheet metal services to the automotive industry amongst others. These prototypes are primarily used for vehicle and rig testing as well as manufacturing process development and Chasetead are therefore ideally placed to assist the fundamental prove out of this technology.

Through an understanding of existing processes and equipment for high volume manufacture the opportunity has been identified to produce sheet metal parts without the need for dedicated tools. This technology has been shown to be capable of producing a wide range of axisymmetric parts without a mandrel and as the understanding of the necessary toolpath generation algorithms increases, through the work of academic consortium member Bath University, asymmetric geometries are becoming increasingly accessible and reproducible, (Loukaides and Russo, 2017). This new capability will allow this disruptive technology to replace the deep-drawing press which requires expensive and wasteful dedicated tooling. It will make fast and cheap prototyping possible and is entirely congruent with a digital manufacturing / Industry 4.0 philosophy by eliminating the tooling phase from the development process. Should the project be successful, wide-scale and rapid deployment of new designs to distributed manufacturing locations becomes a reality for the first time.

The application of mandrel-free spinning is not restricted to current production models. A significant number of end of life vehicles rely on legacy tooling for the purposes of service and repair. Tooling for such vehicles as well as those for special versions, prototype builds and niche volumes needs to be stored and maintained. It is estimated that this will cover approx. 60% of Nissan's vehicle line up.

Importantly, the automotive industry will most likely not be the sole beneficiary of the benefits available through mandrel-free spinning technology. The technology will open up opportunities in other sectors, (where previously the use of spun components has been prohibited due to tooling investments) such as aerospace, defence, medical, pressurised container, infrastructure, rail etc. Moreover, addressing the challenge of die-less forming in the automotive industry may well lead to new machine concepts that extend the capability of existing technologies.

5.2.Industrial ecosystem

Relationships between customers and suppliers in the market for sheet forming can be described in terms of the industrial ecosystem. This concept describes a dynamic structure of interconnected organisations that depend on each other for survival (Moore, 1993). Mapping the entities within the ecosystem concurrently with technology development can provide valuable early insights into the implications of new technology and its impact. Entities are the individuals, groups, providers, suppliers and customers engaged in transactions with the organisation. These entities may be internal or external to the organisation implementing the technology. Figure 6 shows Nissan's worldwide network of assembly plants and the vehicles produced at each location.

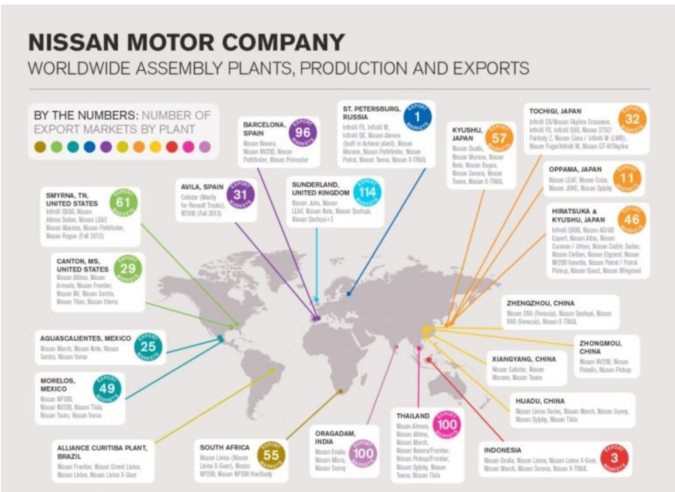

Figure 6 Nissan Motor Company, worldwide assembly plants, production and exports (courtesy of Nissan Motors)

Whilst this figure does not in any sense represent the full production ecosystem of parts distribution and suppliers, it is clear that the ability to instantaneously release CAD files to multiple manufacturing locations for immediate manufacture by die-less forming has a profound impact on the organisation's agility and ability to serve its markets.

6. Conclusions

Whilst the technology of mandrel-free spinning creates immediate benefits for the process owner, the implications of its adoption are also felt beyond the immediate manufacturing operations environment and may include knowledge management, skills development and customer relationships. This paper has attempted to elucidate some of the impacts on supply chain relationships for technology developers and their industrial partners and urges them to consider the implications for wider business processes concurrently with technology development.

The primary outcome from this paper is the need to consider simultaneously both the introduction of disruptive technology, its implications for the organisation and the broader opportunities it may present when implementing breakthrough innovation. Mapping the industrial eco-system around new technology is important to identify where impact will be felt. Illustration is provided from an automotive supply chain of how this process can benefit supply chain agility.

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