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TOOLLESS LAYER-WISE PRODUCTION METHODS - ADAPTABLE AND FAST WAY TO CUSTOMER

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Abstract: *In this paper we present basic concepts and a simple analytical treatment how Additive Manufacturing (AM) methods and other toolless layer-wise techniques can be used to reach customers fast and without large capital expenditures. As a fundamental approach, the product specific tooling (hard or soft) will be developed when the volumes justify them. As an example, we consider practical and commercially successful cases where Incremental Sheet Forming (ISF) has been applied to manufacture high quality sheet metal components. We will present a mathematical treatment starting from simple concepts that will describe the process starting with the toolless production methods and then converting to more conventional production. We will then expand the treatment to take into account current business forecasts dynamically.*
Key words: *Additive Manufacturing (AM), Incremental Sheet Forming (ISF), Transfer to Manufacturing, Tooling Justification, Production Planning*

1. INTRODUCTION

Additive Manufacturing (AM) is a common name for many techniques that can be applied to make 3-dimensional shapes automatically without the need to make the shape defining tools in advance (Wohlers, 2009). Originally the AM techniques were applied to prototyping in many industries. Due to improvement of those techniques and materials, AM can now be used also for production in many applications. However for large production volumes, AM techniques are more expensive than conventional techniques that apply custom made tools (Hopkinson & Dickens, 2003). Here we consider cases where AM techniques are used for production in initial phase when the future production volumes are uncertain.

For sheet metal components there are a limited number of techniques that can be used for prototyping and short series manufacturing. Incremental Sheet Forming (ISF) is a technique developed for this purpose. It is a layer-wise and in many cases toolless manufacturing method, due to witch it has been classified under AM-techniques in the sheet metal forming context (Masuku et al. 2005).

2. BREAKEVEN QUANTITY

In a previous report (Tuomi & Vihtonen, 2007), we have presented 12 commercial cases where Incremental Sheet Forming has been used for industrial purpose. Many of the cases were sheet metal components for heavy and mid-heavy industries like for machine tools, tractors, and forest harvesters. We have reprinted the relevant cost data in Table 1 below. In the first 9 cases the ISF was used for prototyping and last 3 were for production or tooling.

Here we present a common analytical treatment how to evaluate the decision whether to use toolless layerwise production methods like ISF or to use more conventional tooling methods. Especially, we develop production planning techniques for the case where we can delay investment costs by using toolless methods in the early production when the total expected business is very uncertain. Later when the business outlook is more predictable we convert to more conventional tooling.

Case No	ISF tool cost	ISF part cost	Conv. tool cost	Conv. part cost	Breake. quantity
1	0,3	40	7,5	14	280
2	3,9	390	20	36	45
3	1	240	50	120	410
4	1,2	50	10 kú	28	400
5	1,3	570	49,9	30	90
6	3	400	48	280	380
7	0,9	210	50	120	550
8	0,1	150	9,8	9	69
9	0,49	460	38	20	85
10	2,85	390	100	30	270
11	0,3	190	100	20	590
12	0,7	125	40	25	390

Tab. 1. Cost data from ISF Case studies (Tuomi & Vihtonen, 2007)

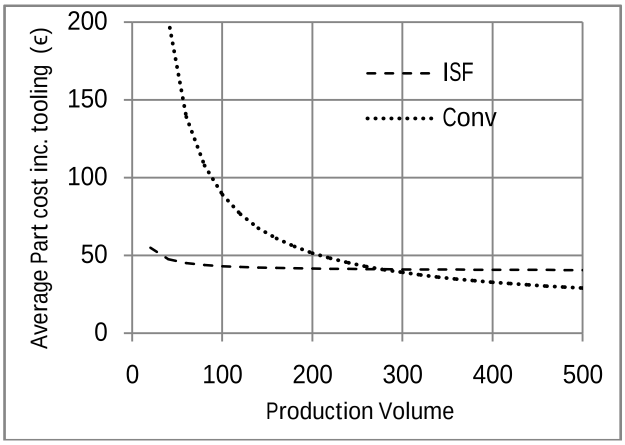

Fig. 1. Average part cost including tooling as a function of the production volume for Case 1 in Table 1

Toolless methods are typically more economical at small quantities and conventional methods cost less when the quantities are high (Hopkinson & Dickens, 2003). As an example, we take *Case 1 (Table 1)* and calculate the average part cost taking intoa account both the tool cost and individual parts´ material and process cost. The average part cost including tooling is shown in Figure 1. The two graphs cross each other at the at the production volume value that we call the breakeven quantity, N_B. It is the production volume value where the costs are same for the two potential methods. Obviously, if the number of parts to be produced is known beforehand, N_B can be used to decide which method is more economical to use. When the total production is lower than N_B

a toolless method should be used and in the opposite case a conventional method makes more sense. It is easy to show that the breakeven quantity N_B can be calculated for the case of Incremental Sheet Forming using the formula

$$N_B = (C_{CT} - C_{ISFT}) / (C_{ISFP} - C_{CP}) \quad (1)$$

where C_{CT} and C_{ISFT} are the costs of the conventional tool and the ISF support tool, respectively. C_{CP} and C_{ISFP} are the production costs per part of the conventional method and the ISF method, respectively. We have shown also the breakeven quantities N_B for the cases of Table 1. So in the 9 first cases of Table 1 the person in charge of production probably new that the total production is significantly larger than the breakeven quantity; so that ISF was only used for prototyping and the production was done with conventional tooling. The last 3 cases the production quantities were smaller than N_B and ISF was used for production.

3. EARLY PRODUCTION WITH TOOLLESS METHODS

The accurate knowledge of future business volume is not common for new products. Investing in expensive tooling in advance is not reasonable if you do not know whether the future business will justify the expence. In the cases where the total production is not orders of magnitude higher than N_B, starting the production with toolless methods makes sense. Then when the business seems to follow the plan we would convert to conventional tooling. We will here present an analytical approach that mitigates the risk and aids in defining the moment to introduce the conventional tooling.

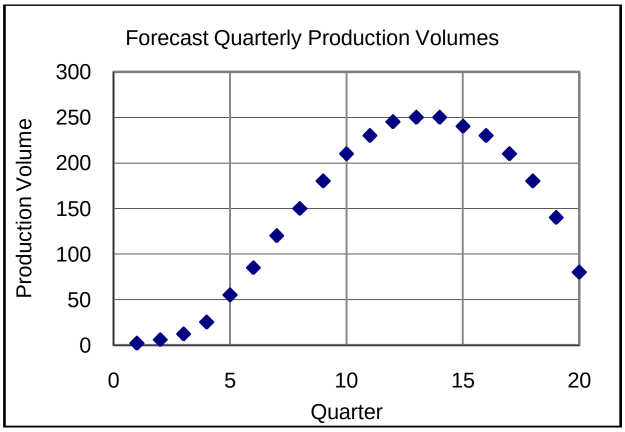

Fig. 2. Production Volumes for the example presented in the text

We study a theoretical case of new product development in terms of breakeven quantities, production rates, and time schedules that follow theat cases of Table 1. Let's assume th the initation of production the business analysis lead to the complete life cycle production forecast that is shown in Fiqure 2. We also assume that breakeven quantity, N_B, for tooling has been calculated to be 300.

First we consider the case where the conventional tooling is procured in the beginning of production. Looking the data of Fig. 1 we can evaluate that the breakeven point will be reached in 7 quarters. This means that we are investing tooling costs with 21 month payback time based on forecast that was done without any market acceptance feedback. The forecast after 1 year production could look very different, either in good or bad direction. Additionally, there might be need for small changes in design that make the payback time even longer.

Next we will look into the production plan that involves a toolless method for early production. We will look into a case that we wait until to the beginning of 6^{th} quarter before we get the production tools. 300 production unit breakeven point will now be reached in less than 8 months. Also, the confidence on the forecast is now much higher because we have significant market acceptance feedback from 15 months of production. Additionally, we can now calculate cost this financial risk reduction approach. The cost can be easily expressed in terms of tooling cost. We used toolless method for 5 quarters generating 100 units. Because the breakeven quantity for the tooling was 300 units the additional cost for the toolless method was 33 % of the total tooling cost. So even in the unlikely case that the original forecast is exactly right, mere 33 % effective increase in tooling cost would yield remarkable reduction in the financial risk. With possible design changes, the cost increase might even become in effective a reduction.

4. USE OF DYNAMIC BUSINESS FORECASTS

In the next step we make the treatment more general by introducing a scaled payback tim

$$ŭ \quad _B \neq t_L \quad t \qquad (2)$$

where t_B is the payback time and t_L is the selling life of the product. For the first case of immediate conventional tooling we can calculate ŭ = 0,35 (7/20 case of initial toolless produc quarters). So, ower is the risk. A very er ŭ i useful point of this approach is the feature that the production manager can always use the latest sales forecast in calculating the scaled payback time ŭ and re first estimate, when the scaled payback time ŭ reach 0,25 or below, seems to be a resonable moment for introducing the conventional tools.

5. CONCLUSION

We have presented here how new and emerging toolless production methods can be utilized early production in order to reduce the financial risks involved in making the production tools. We have used commercially applied cases of Incremental Sheet Forming as a starting point for the analysis although it applies also to all Additive Manyfacturing technologies. Additionally, we show how to reduce financial risks using always the latest production forecasts.

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