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IMPLEMENTING REDUCTIONS IN DIE CASTING CYCLE TIME: A CASE STUDY

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Abstract

In this paper we will highlight the progress made in reducing machine cycle times in High Pressure Die Casting, across two industrial partners. This paper will highlight the general methodology developed, and how a combination of computer simulation, production intuition and process understanding helped to obtain significant results from the project.

Introduction

Reducing casting cycle time in most cast-shops is critical to improving productivity. In this paper some of the work involved with investigating and implementing cycle time reduction in High Pressure Die Casting (HPDC) will be highlighted. These machines operate essentially as large injection moulding machines, solidifying molten metal, in this case aluminium, between two steel dies. The molten metal is delivered by a ladling robot or dosing furnace. The solidified part is removed via an extraction arm, while several other machine components provide ancillary functions. HPDC provides good quality castings at good productivity rates, due to the relatively short machine cycle times. As with every process though, there always exists potential to further improve productivity. Utilising a combination of new simulation technologies and process intuition, the practicalities of cycle time reduction in HPDC will be demonstrated.

Reducing machine cycle time in HPDC invariably means speeding up the machinery and reducing the component bottlenecks. Nonetheless, it is undesirable to speed up the machine sub-components and find the machine subsequently suffers from increased downtime or the cast parts are of poorer quality. Indeed, the aim is to make the process faster, whilst maintaining or improving the product quality and machine downtime.

This work is a summation and continuation of some earlier work [1,2]. Some other authors have touched on the subject of cycle time [3,4], but few have provided detailed accounts of reductions in cycle time in practice. Two key techniques have been applied in the progress of this research, namely discrete-event simulation to assess the machine loading and critical path in the machine, and finite difference temperature modelling to assess the likely effect on temperature, and hence quality, through reductions in cycle time. This paper will discuss these technologies briefly, before detailing the practical results.

Methodology

The first step required during the project was to develop a systematic methodology to analyse and identify areas for cycle time reduction. The general aim was to systematically identify the steps required to reduce cycle time in practice. This included incorporation of many of the analysis tools developed recently to pre-emptively identify solutions to many of the likely potential problems. This methodology was as follows:

1. Document and monitor the current cycle time. A standard method of timing components has been developed based on the movements of each component in the machine.

2. Determine the interdependencies between the machine components and when they occur.

3. Develop a timing model of the machine to determine the critical path of the process.

4. Systematically plan the reduction in cycle time by examining each step on the critical path. Determine at what cycle time, the machine sub-components become overall bottlenecks to the machine. Take into account issues [illegible] quality and maintenance in the plans.

5. Determine likely potential problems an[illegible] solutions to these problems.

6. Perform trials and implement the plans developed above.

7. If the critical path changes, go back to step 4 until the cycle time can be reduced no further, whilst providing a stable, reliable process.

Much of the focus in this paper will not be on the methodology, but on the application of this methodology in practice. Focus will therefore be mainly on steps 4 to 7 in the above methodology.

Timing models

The main form of timing model developed has made use of a commercially available discrete-event simulation package called QUEST. From this modelling package a generic model of HPDC was developed, Figure 1, so that several key features of the machine could be extracted quickly. These were: a) a fast and effective method for assessing the reduction in cycle time, b) utilisation levels on the various sub-components, and c) the overall machine critical path. As shown in Figure 1, this generic model which contained all the standard sub-components for relatively old machines: a) Ladle and ladle arm, b) hydraulic piston, c) fixed and moving dies, d) overhead extraction mechanism and rail, e) sideways die spray boom and f) rough trim press. While other die casting machines do vary from this design, modifications to the timing can be included to accurately model the process.

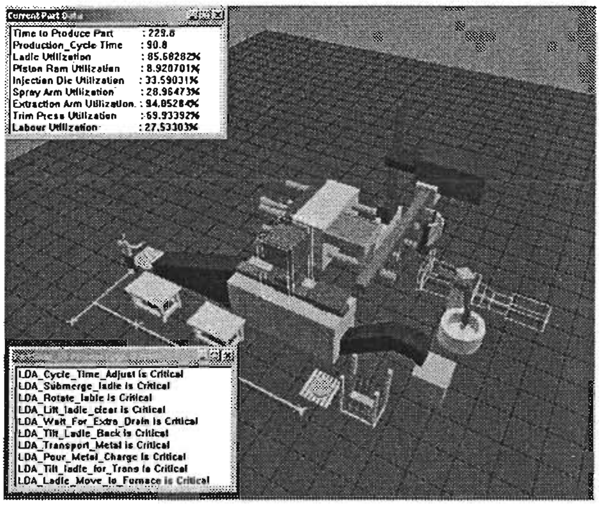

Figure 1. Timing model showing utilisation levels and critical path.

Thermal monitoring and modelling

As well as computer simulation for the machinery, one of the key concerns for quality was related to the effects of reduced cycle time upon temperature. It was clear that a reduction in cycle time would lead to increased die temperatures, but questions related to the quantitative rise in temperature and its effect upon quality could not be answered. Consequently a combination of MagmaSoft modelling, to predict the effect on flow patterns and temperature, and thermal monitoring (Thermal camera and water channel thermocouples) were employed to assess the impact upon temperature during trials. This combination, along with the anecdotal evidence from the trials on key quality criteria, provided sufficient information to assess the impact of temperature.

Application of Methodology

It was decided at the start of the project to progress the methodology and application of techniques by focusing upon one part at each of the two industrial partners.

Nissan Casting

At Nissan the focus was on a small pump cover, with the aim of achieving a 45 second cycle time. Partway through the project, the machines on which the parts were made shifted from two 800 tonne machines to one 1250 tonne machine. A new twin cavity die was designed and run on the 1250 tonne machine, but the combination of die and machine operated initially at a 75 second cycle time. Within a short space of time, this was reduced to just above sixty seconds, through a combination of increasing the speed of various machine components, particularly the extractor, and a reduced solidification time. The solidification time was reduced by the application of thermal modelling to the design of the new die. This new twin cavity die was designed to operate at a short solidification time and a 45 second cycle time. Consequently, four of the die cooling fountains had to be turned off to enable the die to function adequately at a 60 second cycle time.

After several months of operation, it was apparent that the extraction mechanism was suffering increased levels of breakdown, due to the high speed of travel into the die area. After some maintenance analysis, the extractor was slowed down when travelling into the die area, in order to reduce the problems with unplanned downtime. Several machine protection items were also added to help prevent a recurrence of the key maintenance issues. The cycle time, however, increased by 5 seconds and further study led to the conclusion that a combination of events had inadvertently increased the cycle time. This episode highlighted an important lesson in not being too overconfident with initial results. It may take several months for issues of machine reliability to become apparent after the initial cycle time reduction.

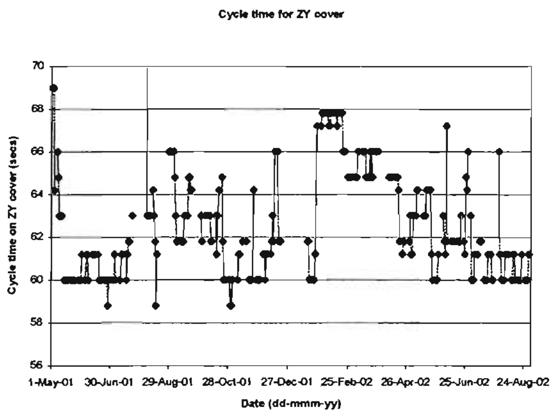

Figure 2. Cycle time for ZY cover

The cycle time was again reduced to just over 60 seconds through speeding up the extraction mechanism in other regions of its cycle, which included the quench, the horizontal traverse speed and the downwards speed into the rough trim press. Further incremental improvements to the cycle time were also achieved over the same period, so a stable cycle time of 60 seconds was observed for a significant length of time. This is apparent in

Figure 2, where a plot of the cycle time is presented for more than one year. This graph highlights the impact on cycle time of the reduction in extractor speeds mentioned in the last paragraph, as shown by the sharp jump in cycle time midway through the graph. While the casting productivity had improved, only minor progress was made towards achieving a 45 second cycle time.

A series of computer simulation experiments were developed that provided a roadmap toward achieving the overall goal. The key findings from the modelling were:

1. Three main sub-components on the machine: a) the ladle arm, b) the extractor mechanism and c) the rough trim press, all became bottlenecks to the system for cycle times just under 60 seconds.

2. It was not clear how small a solidification time could be employed, so the process could be safe and reliable. To achieve a 45 second cycle time a significant reduction in the die open timer would be required.

3. It was not clear what minimum settings for the die lube and subsequent air blow times could be achieved. Again a significant reduction in the air blow time was required to achieve a 45 second cycle time.

4. The increased labour utilisation at 45 seconds meant that a significant drop in the volume of work required for labour was required.

From the above analysis, a series of steps were put into practice to address each of the issues. All the sub-components were studied in detail to determine where the cycle time on each of their cycles could be improved. This involved much questioning of the base operation of the machine. A series of production meetings helped to identify and focus on each individual issue. These meetings allowed for ownership of the project to be balanced between the researchers and production personnel, and for the initiation of trials to achieve results. The details of some of these trials will be discussed later.

The issue of solidification was solved through the combination of magma modelling and production intuition. It was apparent that when the twin-cavity castings were produced at a 60 second cycle time, the only section of the casting that showed evidence of not fully solidifying was the biscuit and lower runner area. Examination of the water cooling around the sprue bush and along the sprue post indicated that the cooling was inadequate in this region. A new sprue post and bush system was then designed, with a total of six fountains added to the two die inserts. The new inserts were trialed in production, and the result was little evidence of small expulsions of metal that had been previously observed. Thermal monitoring also suggested a significant drop in temperature around the sprue post region.

Magmasoft was used to answer the question of what was the minimum die open time, or the safe solidification time. Through a series of simulation experiments, it was possible to determine that the safe die open time was 10 seconds, operating at a cycle time of 55 seconds. The results of this can be observed in Figure 3, where the darker grey area represents the semi-solid metal, which is likely to lead to metal expulsion if it is too large.

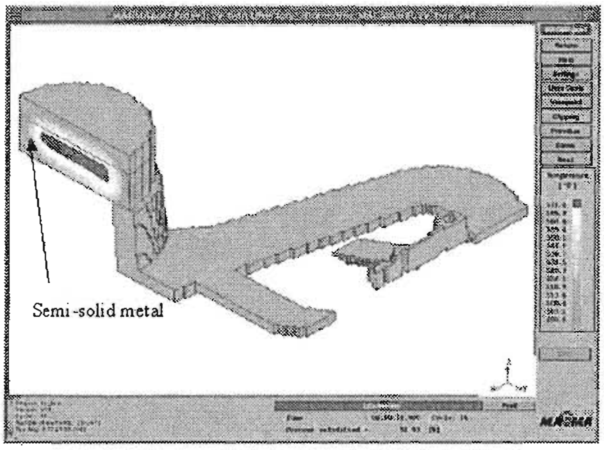

Figure 3. Magma results of sprue post at 55 seconds.

Two production trials were run to assess the problems and potential of operating at a 45 second cycle time. The results of the first trial showed that a cycle time of 55 seconds was achievable with minor modifications to the operation of the casting machine. A second trial later in the year, built on some of the gains of the earlier trial, and observed a cycle time of 53.5 seconds. The conclusion of the trials was the determination of three key sets of understanding. Solutions have been developed to circumvent these problems. The main results of the trial were:

- The overhead quench of the extract arm could be bypassed, but significant steps had to be taken to cool the casting before the operator handled them. The runners had to be cooled prior to the rough trim press, in order to break from the casting rather than bend.

- The air blow time, after die spray, could only be reduced to a level that didn't allow water staining or porosity. Experimentation had suggested this was not at too low a level.

- Further improvements to the sprue post cooling have the potential to reduce the die open time further.

Ford powertrain operations

At Ford, there was significant emphasis on cycle time reduction with the anticipated increase in production volumes with the new model cars that came on-line in September 2002. The HPDC section at Ford operates in a different market to the Nissan casting plant. At Ford, the aluminium casting section is one part of a considerable supply chain to the engine assembly area. Their production volumes and part mix are determined by the sales of the locally produced cars, and the component design mix for the engines.

The focus of the cycle time project started with the structural sump. All the casting machines are 2250 tonne capacity, and the structural sump operated at initially a 115 second cycle time. This sump casting was of considerable mass and involved the operation of three sliding cores with the die. Operator intervention was routine, due to a build-up of flash on the dies and the part suffered from a number of critical quality features. Production gains had reduced the cycle time down to 105 seconds, and a series of trials had been run to indicate a cycle time around 95 seconds was feasible. The issue of flash build-up and operator intervention, in manual spraying of the dies, could not be resolved, and so gains beyond a cycle time of 105 seconds was not possible. Some cracked sliding-cores made the pursuit of further reductions in cycle time untenable, due to the high risk of further damaging the remaining cores.

The project therefore shifted focus from the large structural sump, to a smaller converter housing operating in the next machine. Using the simulation model described previously, initial modelling showed a cycle time of just over 90 seconds, with high utilisation on the extractor and ladle arms. The critical path was associated with the robot ladle arm, as the cycle time adjust timer was being used to control the cycle time. A series of steps were proposed to reduce the cycle time down to 70 seconds, based on the key bottlenecks within the machine.

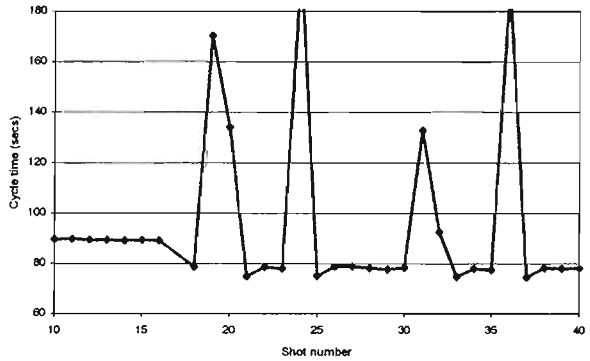

Figure 4. Cycle time during first trial on the converter housing

Trials were set up and run, the results of the first trial are shown in Figure 4 and have been obtained using data from a shot monitoring system. These results show a reduction in cycle time from the initial 90 seconds down to around 78 seconds. The excursions from the cycle time of between 80 and 90 seconds were due to delays during the trial, leading to a time-out delay and the ladle returning to the holding furnace. The timing starts from shot ten due to initial delays implementing some of the cycle time reductions. As can be seen the trial highlighted a ten to twelve second reduction in the process cycle time. At this point the extractor was essentially the bottleneck to the process. During the course of this trial, it was noted that the operator was happy to have a shorter cycle time, as opposed to previous trials for other parts. This was due to the low utilisation of the operator (around 30% busy). Further incremental gains were achieved with the introduction of small improvements to the operation of the extract arm, and the trim press. The final cycle time for the part in question remained between 76 and 78 seconds for the remainder of the project.

Overall, the project has been relatively successful, delivering cost savings of the order of several hundred thousand dollars to the two respective industrial partners. If the technology and methodology was now to be deployed across all the other machines, several million dollars savings could be achieved through a combination of direct cost savings and increased capacity providing further opportunities for extra revenue.

Conclusions

To achieve the aim of reducing casting machine cycle time in High Pressure Die Casting, the authors have taken a systematic approach to solving many of the problems encountered. Starting with a generic methodology, the authors have been able to develop systematic timing charts, utilise simulation models for assessing process critical paths and predict likely changes to temperature, and implement a series of plans developed through the application of forethought and previous learning. Along the way it was discovered that some of the techniques worked well, such as a simulation model for die casting, and some of the issues were surprising during trials. The greatest gains were made in this project when the researchers were located on-site of the industry partners. In the process, the companies have saved considerable sums of recurrent expenditure and were shown methods to improve their productive capacity.

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