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Automation of the Cut Off process in the Investment Casting Industry

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Over the last few decades much effort has been put into automation of different departments of the Investments Casting Industry, especially in wax and dipping. One area that is still in the "dark ages" in regards to automation is the cut off process. Cut off is an OH&S nightmare for companies due to the risk of injury that it presents for the employees. A W Bell Machinery has devoted a lot of time and effort researching how to completely automate the process thus removing the human involvement. Removing the operator from the process completely however does present a new range of issues and this paper is designed to highlight these issues so that there can be better understanding of what is required to be able to facilitate automation.

To this day, cut off in this industry involves either the operator holding the tree and presenting the tree to the abrasive wheel, or having the tree clamped and the operator controlling the motion of the tree remotely. The first is dangerous due to the close proximity of the operator to the abrasive wheel and the manual handling issues due to supporting the casting while cutting off. The second, whilst improving these issues, does not remove the operator from the process and consequently leaves it open to operator error. It is also very difficult to completely enclose the machine to protect the operator whilst giving them the visibility and functionality required to cut off successfully.

Automation overcomes both of these issues as once the tree has been loaded into the machine the operator is then completely isolated. This allows for complete protection of the operator from coming in contact with the abrasive wheel and protects them from sparks and fragment of wheels that may shatter.

Even though in one case study there has been an increase in production rates compared to manual cut off processes of approximately 100% it must be noted that this may not always be the case when implementing automated cut off processes. Due to many of the micro aspects inherent in the process that are listed below, it has been found that it is very difficult to rapidly increase production and maintain consistent cutting that will not produce scrap. What it does allow though is for the operator to continue another task whilst the parts are being cut off from the tree, i.e dual tasking. As it is well known the major cost for any investment casting company is labour. Reducing this cost enhances the companies ability to remain competitive within the industry.

One of the important aspects in automation of the cut off process is that it should be treated like a machining process. Like machining, the part (tree) has to be presented to the abrasive wheel in the same position every time. If not, high levels of scrap can be produced very quickly. Not only is the dimensional accuracy of an investment casting part important, but now the dimensional accuracy of the entire tree assembly is critical. A machine is not capable of adjusting for inconsistencies during the investment casting process that occur before the cut off stage. Therefore to allow automation of cut off to be successful, a mind set change is required across the entire process, especially when the wax moulds and tree assemblies are produced.

Using the current methods, the following process elements become critical. These are processes that are usually not given much attention to.

Firstly when the runner system is produced, very little attention is given to the handling of the sprue when the wax is still in its plastic phase. This can lead to bowing along the axis of the sprue (see Figure 1) which will leave less clearance for any wheel deflection that may occur. Simply modifying handling techniques while the sprue is in its' maeallable phase can dramatically improve the straightness of the tree therefore determining how successful the cut off will be.

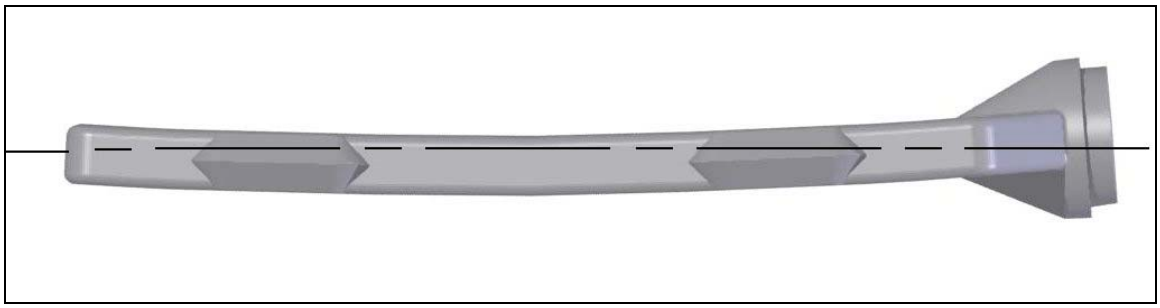

Figure 1 – Example of bowing along the axis of wax sprue

Secondly, how the wax parts are assembled onto the sprue can determine how successful the process will be. When the parts are attached to the sprue very little attention is given to how the orientation of one part is relative to the other parts. If a part is put on so that it may overhang into the cutting clearance area (see Figure 2) then this part will be scrapped during cut off. Also the layout of how the parts are assembled onto the sprue can be critical. If the same layout is produced consistently then a more consistent cut can be produced from one tree to another. One option available to assist obtaining consistency and uniformity of the sprue layout is to incorporate the use of an automated pattern assembly machine.

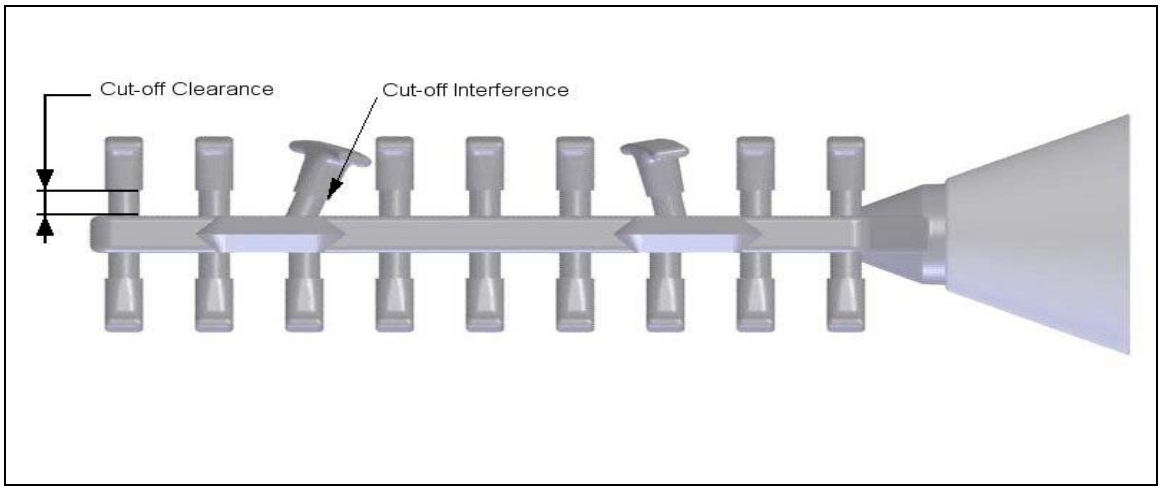

Figure 2 – Interference in the cut off area

In presenting the tree to the wheel a lot of research time has been dedicated to how to hold the tree so that the orientation of the tree is correct every time. This is a difficult problem to overcome due to the wide variety of investment casting sprues that are used across the industry. The first part of the tree that was investigated, that is constant to all trees was the pouring cup. This proved unsuccessful due to a number of reasons. Firstly there is no way of guaranteeing the orientation of the tree when it is loaded into the machine and changing the shape of the pouring cup causes other problems during the pouring of the metal. Secondly, as there are high forces during cutting, holding the tree by one end means that the tree can move around, again which does not allow consistency of cutting. Thirdly, during the casting process there is a chance of short pour of the cup, or for the pouring cup to be completely missing after the knock off process.

A W Bell Machinery has introduced a V Block system along the axis of the sprue (see Figure 3). This has proven to be very successful in allowing the tree to be clamped securely and still to be presented to the wheel in the same position every time, and without relying on the human eye to line up the cut.

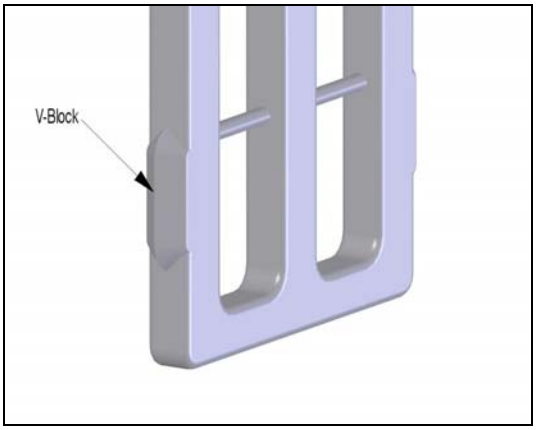

Figure 3 – V Block along axis of sprue

The most effective method of cut off that is currently used is the bonded abrasive wheel. In using this technology it has been found that there are a variety of issues that arise when using abrasive wheels in automating the cut off process for investment casting.

In order to achieve consistency in an automatic process, there needs to be consistency from the abrasive wheel. This requires not only that the correct abrasive product is chosen for the work piece material, but that the machine can meet the required operating parameters of the product. Therefore all the cutting variables can be separated into three main areas, work piece, abrasive wheel, and machine, as displayed in the table below.

Workpiece	Abrasive Wheel	Machine
Hardness	Abrasive type	Peripheral speed
Ductility	Grit size	Cutting rate
Ingate size	Hardness	
Ingate shape	Bond	
	Reinforcement	

Variables from each of these areas need to be matched so that a number of results are achieved. These include characteristics such as wheel life, cutting time, heating of workpiece, cut deviation and required machine power. This process of achieving optimum cutting results should be done in a number of steps:

1. Select the abrasive wheel properties, as governed by the workpiece material. General trends for this selection are shown in the Figure 4 below:

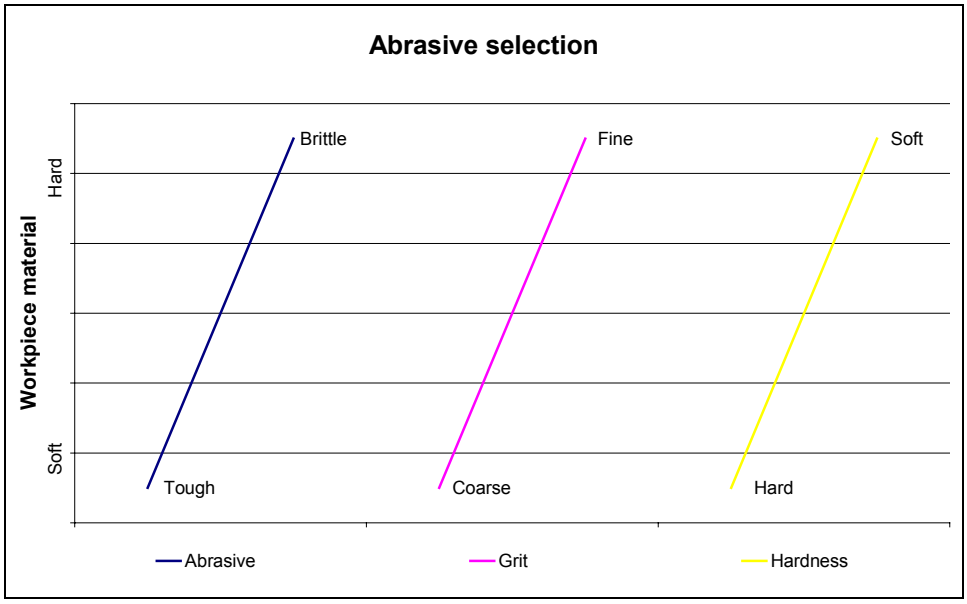

Figure 4 – Abrasive Wheel Selection

2. Through testing, establish the optimum machine operating parameters, i.e. feed rate and wheel periphery speed. Figure 5 below shows the effect these parameters have. Note that increased feed rate can lead to increased wheel deflection as the load on the wheel increases. However, insufficient feed rate for a given wheel bond structure can also lead to deflection as the wheel fails to break away efficiently, leading to a pointed tip which can 'run off' the work piece.

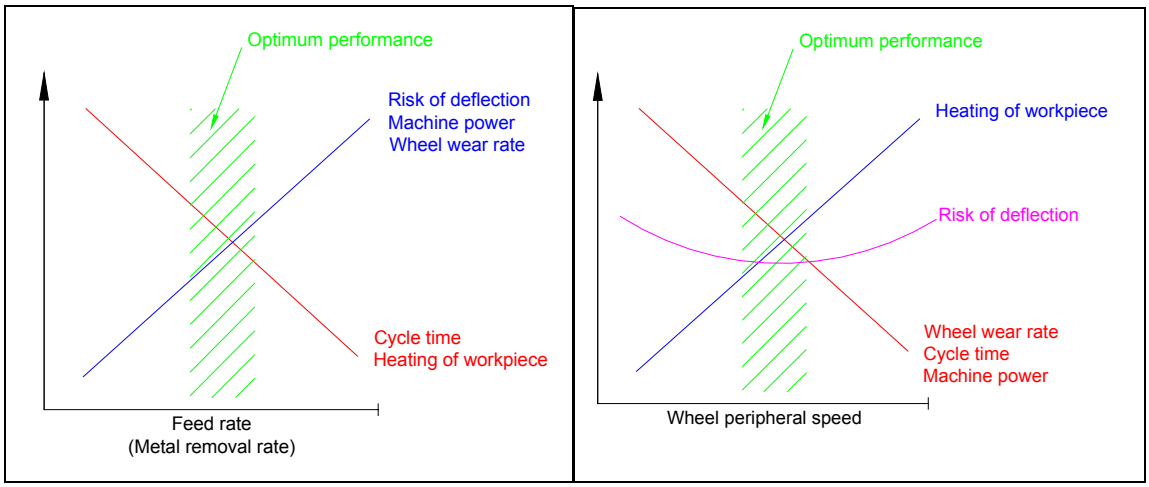

Figure 5 – Machine operating parameters

3. Adjust the wheel bond and reinforcement structure to improve cutting results, i.e. wheel life and work piece burn.

4. Re-adjust the machine parameters to achieve optimum cutting based on tool adjustments.

Achieving optimum cutting is very heavily governed by the correct choice of cutting wheel. A W Bell Machinery have given the automated cut-off saw fully programmable feed rate and wheel edge speed control so that this wheel selection is not limited by machine parameters. Another important feature that our automatic machine incorporates is a wheel measuring sequence, allowing the wheel edge speed to be adjusted at the completion of each cycle to maintain the same cutting characteristics from the first to the last cut.

Getting the right composition of machine and abrasive wheel for the job is not necessarily the only crucial process in automating the investment casting cut-off area. There are hundreds of cut-off machines on the market capable of cutting metal bar stock, many of which operate successfully with general purpose cut-off wheels. The difficulty arises when cutting numerous cross sections of varying shape and size, as found in investment casting. It is the issues that arise from these work piece variables which make wheel selection critical. The major concern arising from cutting investment cast trees is wheel deflection. A W Bell Machinery has investigated why this wheel deflection occurs and what can be done to combat it.

Take a single part with a cylindrical ingate (Figure 6).

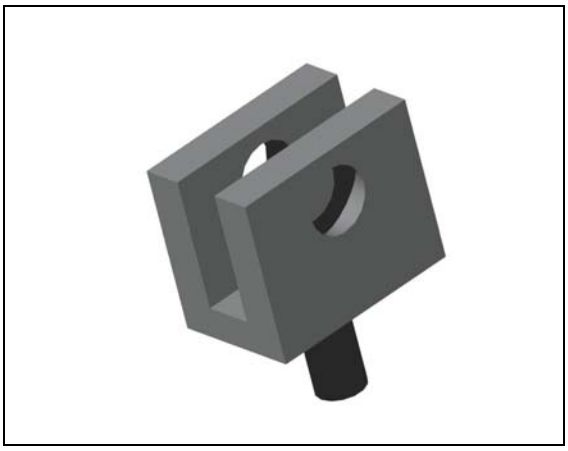

Figure 6 – Example Investment Casting

As the cut progresses through the ingate the tree is supported rigidly on one side of the cutting wheel while the part is free to move on the opposing side. As the metal heats up during the cut, the part tends to peel away from the wheel, no longer providing support to both sides of the wheel. The friction between the wheel and the fixed side of the ingate therefore deflects the wheel. This effect can occur with small and large ingates and is influenced by the amount of heat build up in the gate (See Figure 7).

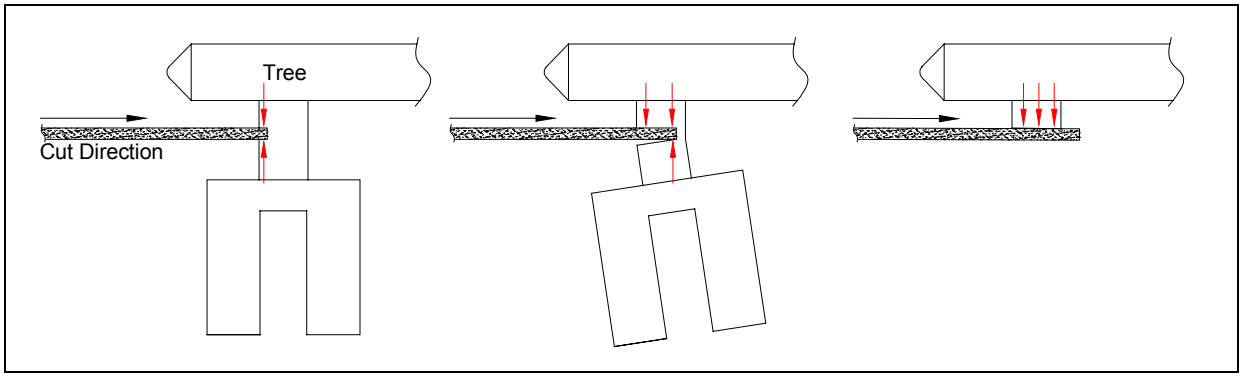

Figure 7 – Forces on Wheel During Cutting (one ingate)

A typical investment cast tree however consists of more than one part. Therefore the cut-off procedure requires the wheel to cut numerous ingates in one pass. This leads to a compound of deflection from each ingate cut, which also becomes more acute as the cut becomes deeper and therefore closer to the wheel spindle. This is shown in Figure 8.

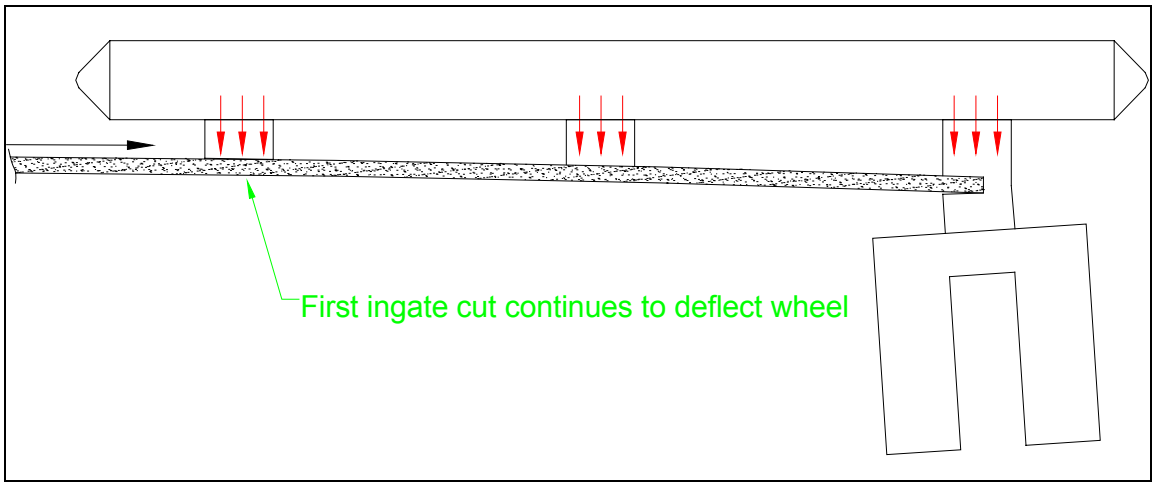

Figure 8 – Forces on Wheel During Cutting (multiple ingate)

The other major cause of deflection in the cutting of investment cast parts is the lack of uniformity and the presence of angles in the gating systems. Gates have typically been designed with the efficient flow of metal in mind with little thought to how this may effect the cut-off process down the line. There are two ways that this type of gating affects the cutting process.

1. Irregular cross sections or tapered gates: Gates with irregular cross section between the tree and the part result in uneven pressure on the cutting wheel. The gate is generally larger on the tree side of the wheel, resulting in deflection away from the tree.

2. Angled faces on gates: If you ask any abrasive wheel manufacturer how to achieve a straight cut into an angled face they will tell you that it is near to impossible. While reinforcements can help, all abrasive cutting wheels will flex under side loading. Therefore it can be expected that when cutting into an angled gate deflection will occur due to the side load exposed to the wheel as soon as it touches the work piece (see Figure 9). As the cut progresses this deflection continues to increase as there is no means for relief. 'Scoring' of the angled face can reduce this deflection slightly, however this is very difficult to implement as there is no means to determine exactly when a gate will be encountered by the wheel, due to both irregularities in gate position and the fact that the abrasive wheel is continually wearing.

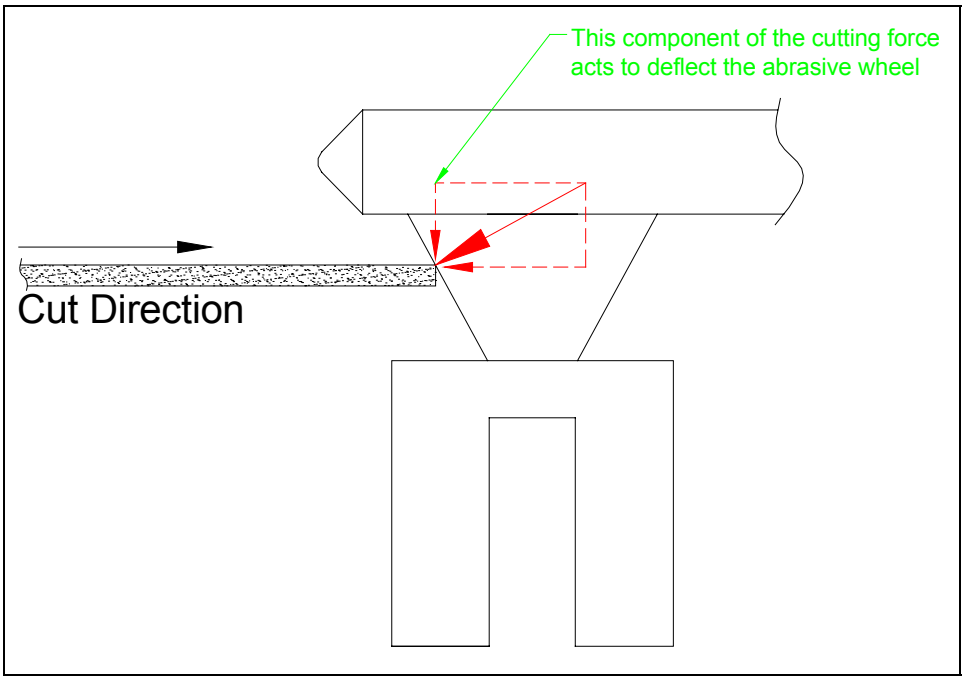

Figure 9 – Cutting of Angled Ingates

Another factor that must be taken into the consideration when cutting into angled ingates is the uneven wear that may occur on the edge of the wheel. As can be see from Figure 9, the top edge of the cutting wheel will make contact with the ingate first. This may result in faster wearing of the wheel on this edge. Once non-uniform wearing on the edge of the wheel occurs then it can be difficult to obtain a straight edge again. This means that even if straight ingates are cut into after inconsistent wear is present there will be wheel deflection issues that may arise. Areas have been looked at by wheel manufacturers such as dressing and specially designed wheels that wear consistently along the cutting edge. Both of the these methods are difficult to obtain, however, and will result in the wheel being used at a higher rate than normal, therefore reducing the efficiency of the entire wheel.

Deflection of the wheel during the automated cut off process when cutting through all of the gates on a tree needs to be kept to a minimum. This is because it cannot be predicted exactly where and to what degree the deflection will occur and it is very difficult to make automatic adjustments for any deflection that may occur. The solution is to allow for a certain amount of wheel deflection across the cut and add this value onto the process tolerance. The next issue is to maintain the wheel deflection within this specified amount as even a small deflection at the wheel edge can result in large deflections as the cut progresses. To eliminate this, A W Bell Machinery's testing has lead to providing relief on the tree side of the cutting wheel through an angle of attack. Using a 24" depressed center wheel, it was found that an angle of attack of approximately 0.6º is sufficient to cut a large range of ingates successfully. This allows for approximately 2mm (0.079 in) deflection on a new wheel. As the wheel wears this clearance reduces linearly, however the moment arm acting on the wheel also decreases, resulting in less deflection.

The effect of this angle of attack is shown below. As the first part is cut the wheel deflects, however the loading on the side of the wheel reduces as the wheel continues moving over the part to a point where the side force no longer exists. The wheel then deflects as it cuts the next part, and so on. This results in a deflection graph similar to Figure 10, with the wheel cycling between zero and its maximum deflection.

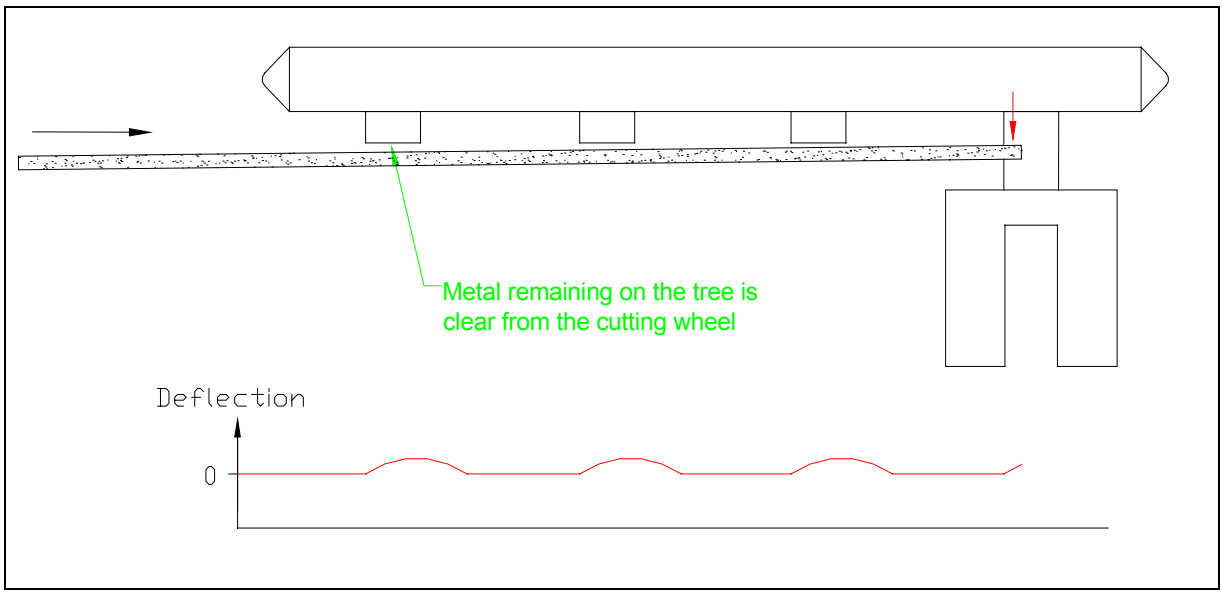

Figure 10 – Deflection Graph

Obviously there are limitations to how effectively this works. If the maximum deflection is experienced on one gate it must be completely relieved before the next gate is hit. If the gate spacing does not allow this then it will result in compounding the deflection. This problem was particularly pertinent to the cutting of angled gates where large deflections are common. However, our results have shown that for a vast majority of parts this solution proves very successful, providing consistent and repeatable cutting.

The big question that arises from the above characteristics of the abrasive wheel is: "What can be done to overcome the deflection of the abrasive wheel?" This is a question that is being worked on closely with the various wheel manufacturers. The choice of getting the correct wheel for a certain process is the ultimate responsibility of the end user. However to further improve the tolerance when cutting using this automated technique, A W Bell Machinery has been working with wheel manufacturers using a new shape cutting wheel. Rather than giving the wheel an angle of attack via adjustment of the spindle, the type 27 depressed center wheel has been modified to become more of a saucer shape (see Figure 11). This will mean that the entire edge of the wheel is at the same height, rather than the variation that is currently being experienced with a flat wheel. If successful the cutting tolerance utilizing an automated process will be reduced even more. Unfortunately the technological advancements are not yet at the stage that can produce an abrasive wheel that does not have deflection. Not far away however, are cutting technologies such as diamond wheel abrasives or carbide tooth wheels that are able to cut at speed without lubrication.

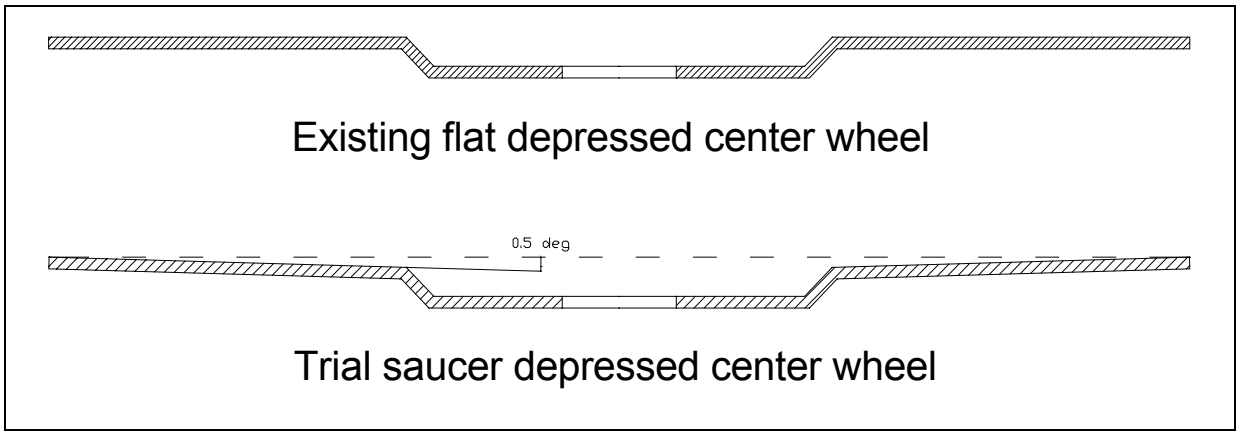

Figure 11 – Modifcations to Depressed Centre Wheel

The major hurdle in successfully controlling deflection of the wheel in investment casting cut-off lies ultimately with the gating of the parts and the minimization of angled faces. While wheel specifications can be altered to help minimize deflection off the angled face, this tends to result in a fast wearing, soft wheel bond, which may become uneconomical.

In the research for future cut off processes it is important not to be restricted to abrasive wheel. Such methods as laser, plasma, and water jet cutting are always being investigated. Whilst most of these methods would eliminate the issues that arise with abrasive wheel cut off, these technologies are not enough advanced to become a viable option for the investment casting industry. Abrasive wheel cut off still remains the most efficient and most cost effective method.

So why not look at robots? Robotic cut off is an area that does lend itself to automation, but robots do not overcome the issues of wheel deflection, and as a consequence will have the same complications. Also a large robot would be required to withstand all the forces that are involved, resulting in high capital costs. Not to mention the fact, for safety reasons, an entire room will need to be built around the machine, therefore taking up relatively high amount of valuable floor space. A W Bell Machinery's CNC cut off machine offers a compact solution at a relatively low capital cost.

Looking at the bigger picture: "Are all Investment Casters able to automate their cut off process?" The simple answer in today's environment is no. Due to a wide variety of casting techniques and the complexity of some gating systems not every system is suited to the automated process. A W Bell Machinery has recognized this and has developed a manually operated saw that addresses as many of the OH&S issues of safety and manual handling as feasible. This machine is unique in it's design in that unlike many other machines, the wheel is presented to the work piece, rather than the work piece being presented to the wheel. This design philosophy change is the reason why the majority of OH&S issues are resolved.

In conclusion, automation of "cut off" can be proven to be a viable option for large number of investment casters, but requires a fundamental change of principles in the entire process to be successful. The future technological developments will only mean that the process becomes easier and more cost effective for all investment casters to implement. With the current trends of OH&S restrictions on the work place, it is not unsurpassable to foresee that in the near future manual cut off operations will not be allowed to continue. The more proactive companies can be to develop their process for automated cut off, the greater advantage they are going to gain over their competitors.