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MANUFACTURING INSIGHTS

Advanced Grinding

SCENE 1. CG: FBI warning white text centered on black to blue gradient	**WARNING** **Federal law provides severe civil and criminal penalties for the unauthorized reproduction, distribution or exhibition of copyrighted media.** **Copyright © 2009** **Society of Manufacturing Engineers**
SCENE 2. SME logo, with music	
SCENE 3. Manufacturing Insights open, with music narration	**MUSIC UP AND UNDER** **NARRATION (VO):** MANUFACTURING INSIGHTS, MANUFACTURING ENGINEERING MAGAZINE'S VIDEO SERIES FOR PROCESS IMPROVEMENT.
SCENE 4. Advanced Grinding introduction	**NARRATION (VO):** IN THIS VIDEO WE TALK WITH SOME OF THE WORLD'S LEADING EXPERTS AND EXPLORE THE TRENDS AND DRIVERS THAT ARE SHAPING THE LATEST ADVANCES IN THE GRINDING INDUSTRY.
SCENE 5.	**NARRATION (VO):** WE LOOK AT CINETIC LANDIS OF HAGERSTOWN, MD, WHO OFFERS A BROAD RANGE OF PRODUCTION CYLINDRICAL, CAM, CRANKSHAFT AND CENTERLESS GRINDERS.

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	NARRATION (VO): AND WALTER GRINDERS OF FREDERICKSBURG, VIRGINIA, A MANUFACTURER OF SOPHISTICATED TOOL AND CUTTER GRINDERS.
SCENE 6.	**NARRATION (VO):** WILL ALSO VISIT STATE OF THE ART TOOL AND CUTTER MANUFACTURING SONIC TOOLS OF ASHLAND, VIRGINIA.
SCENE 7.	**NARRATION (VO):** AND WILL SEE HOW ABBOTT MACHINE OF ALTON, IL, USES ADVANCED GRINDING WITH AN ABRASIVE BELT TECHNOLOGY PROVIDED AND DEVELOPED IN CONJUNCTION WITH 3M. -- FADE TO BLACK --
SCENE 8.	**NARRATION (VO):** THE GRINDING MARKET IS UNDERGOING MANY CHANGES THAT IS BEING DRIVEN BY GLOBALIZATION AND ADVANCES IN TECHNOLOGY.
SCENE 9. LANDIS 05.04.26 – 04.43	**HIKES:** The drivers, as for most industries, are cost, optimizing production, support of our customers' lean manufacturing objectives, achieving higher precision at the optimum cost, and best part throughput.
SCENE 10. LANDIS 05.06.42 – 07.17	**HIKES:** We have many applications where we have taken multiple operations, four or five or six operations, and condensed them into less machines, in some cases one or two machines, which gives the customer more flexibility in their processing.

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SCENE 11.	**NARRATION (VO):** THE TOOL AND CUTTER INDUSTRY VARIES GREATLY FROM PRODUCTION GRINDING; BUT THE INDUSTRY TRENDS ARE SIMILAR.
SCENE 12. WALTER 04.17.26 – 04.18.12	**MARTIN:** A major trend over the last few years are smaller lot sizes. No one wants to stock large inventory, so they demand smaller lot sizes. For example, three-quarter inch tools that previously were made in lot sizes of 50 to 100 are now made in 10 to 20 batch sizes, so that's a driving trend. Also demand on accuracies grows every year. Tolerances that used to be in the range of 1/1000 is now down in the 3/10 to 2/10 range, so again, another demand in the field. Another thing I would like mention is the changing geometries in cutting tools, things such as variable helixes, variables rates, variable clearance angles are being developed that give better tool performance, lower chatter, lower vibration, but of course that's a higher demand in producing the cutting tool.
SCENE 13.	**NARRATION (V0)** JOHN MANLEY SEES THE TOOL AND CUTTER INDUSTRY FROM A MARKETING PERSPECTIVE.
SCENE 14. MANLEY 00.01.57 – 02.27	**MANLEY:** As the automotive manufacturing and aerospace perhaps change batch sizes, in parallel cutting tools are moving toward smaller batch sizes. As a result, people manufacturing cutting tools, people regrinding cutting tools in the service sector, now have to look at smaller batch sizes. As a result, that is putting more constraints on the machine tool manufacturer from a software and hardware perspective.
SCENE 15.	**NARRATION (VO):** THERE IS, ALSO, A MARKET TREND TO VERY HIGH ACCURACY MACHINES USING LINEAR SERVO MOTORS WITH HIGH ACCURACY SCALES AND HYDROSTATIC SLIDES.

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SCENE 16. MANLEY 00.24.09 – 25.00	**MANLEY:** Linear drives are a big trend in the industry right now. In the past ball screws were common technology on machines. We still use them today on most of the manufacturers. The downside with the ball screw is, with the coolant having carbide suspended in it, even with the best filtration systems out there, some contaminants still get onto your ball screws and traditional mechanical wear just from heat in the drive package. As a result, the ball screws do wear, you do get backlash in your system. With linear drives this is very different. It's a backlash free system, where the movements and the accuracy of those movements is completely dictated by the glass scales on the machine.
SCENE 17. MANLEY 00.25.05 – 25.40	**MANLEY:** But the beauty of the linear drive is that you have perfect geometry from day one you own the machine to the last day you own the machine. I look at it, if I were a customer, as I can buy a machine today and I know I'm still producing perfect geometries five years from now.
SCENE 18.	**NARRATION (VO):** CINETIC LANDIS IS SEEING A SIMILAR NEED FOR HIGH ACCURACY MACHINES USING LINEAR SERVO MOTORS AND HYDROSTATIC SLIDE SYSTEMS.
SCENE 19. LANDIS 05.27.18 – 28.13	**HIKES:** In the past, machine way systems were all friction, and friction means loss in any kind of mechanical system. The bulk of our weigh systems on our machines are hydrostatic, which have no sliding friction, and it allows us extremely efficient operation of the axes. We have losses in the axes that are a fraction of what they were in the past. The net power to run the machine is reduced to the point where most of the electrical input energy into the machine is to run the wheel spindle motor, with a very small percentage lost in axis motion.

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SCENE 20.	**NARRATION (V0)** LINEAR MOTORS ARE INCORPORATED WITH HYDROSTATIC SLIDES MAKING THE SYSTEM ALMOST FRICTION FREE, VERY SMOOTH, AND WILL HAVE VIRTUALLY AN INFINITE LIFE. THE LINEAR MOTORS USE SCALE FEED BACK WITH SUB MICRON ACCURACY. THIS HELPS TO MAKE THE MACHINE TOOL THERMALLY STABLE. ANOTHER BENEFIT OF THIS DESIGN IS THAT THE SYSTEM IS EXTREMELY RESPONSIVE AND ONLY DEPENDENT ON THE SPEED OF THE CONTROL TO REACT QUICKLY AND ACCURATELY.
SCENE 21. MANLEY 00.27.33 – 27.55	**MANLEY:** There's another reason we're using linear drives, and that's the trend toward microtools. As you go to microtools, you need phenomenal surface finishes and you need very high accuracy, for example corner radii, on the tool. By using linear drives, we're able to get these perfect finishes and these very high tolerances.
SCENE 22.	**NARRATION (V0):** PROFESSOR STEPHEN MALKIN, OF THE UNIVERSITY OF MASSACHUSETTS IS RECOGNIZED AS THE FATHER OF MODERN GRINDING THEORY.
SCENE 23. Malkin 02.03.58 - 04.31	**MALKIN:** Many times industry is using the process as provided to them by the machine manufacturer, if it's in a production environment, or often by trial and error way by the technical person or machinist in the production system. Surprisingly, not many engineers really understand the process, and that to me is the real problem. It's one of understanding.

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MALKIN 02.26.30 – 27.31	**MALKIN:** Nowadays we understand the grinding process. We have software that can be used in an intelligent way to improve, to optimize the process. It is a complex process; there are many different elements in it. Software allows someone to integrate all of these into a meaningful whole, so they can see what happens during the grinding process.
SCENE 24. MALKIN 02.07.02 – 02.08.37 We need a lot of grinding cut away to show this long scene. Great interview segment!	**MALKIN:** Starting about 40 years ago, there was intense research begun--I was doing this sort of thing too—on trying to understand why grinding is the way it is. Why are the forces what they are, why is the energy what it is, why does it take a certain amount of power, what happens to the grinding wheel during the process, what happens when we dress the wheel, how does the wheel interact with the machine, how does it interact with the work piece, what are the kinematic issues, and so on. All these things by themselves constitute various models or physical descriptions, quantitative physical descriptions of the process. These sorts of experiments and research studies helped us understand what's going on with grinding. But the real problem with using the science is grinding involves interrelated phenomenon. For instance, we start out dressing the wheel. We select the wheel first, even before we dress it. Then we dress the wheel. The dressing process, and how we dress the wheel, has a very big effect on the process. We understand that nowadays. So how we dress the wheel is an important factor, because it determines what the topography of the wheel is and how it will grind.
SCENE 25. 02.09.10 -02.09.55	**MALKIN:** The energy is extremely important not only because it tells us how much power we need in the process, but it's also extremely important in that all this energy we're putting into the process is converted into heat. Virtually all this energy leads to a rise in temperature. So we have to then calculate the temperatures in the process. These temperatures cause thermal damage of various types, residual tensile stresses, and have a very bad effect on fatigue life, fracture strength, and other things of this nature. So in other words, how we grind the part because of temperature controls in many ways the final quality of the part.

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SCENE 26.	**NARRATION (VO):** THE GRINDING PARAMETERS DEFINED BY MALKIN ARE DEFINED BY RATHER COMPLEX PHYSICAL MODELS THAT RESULT IN NON LINEAR RELATIONSHIPS. THESE MODELS HAVE TO BE CALIBRATED FOR THE SPECIFIC APPLICATION AS THE COEFFICIENTS IN THE MODELS WILL CHANGE WITH WHEEL TYPE, COOLANT, AND PART MATERIAL. THE NEXT PHASE WAS TO DEVELOP SIMULATION MODELS THAT CAN BE USED TO HELP IN THE OPTIMIZATION OF A GRINDING CYCLE. SIMULATION COMBINES ALL THESE INTERRELATED MODELS IN ORDER TO ESSENTIALLY SHOW WHAT HAPPENS IN THE GRINDING PROCESS. THE PROCESS CONSTRAINTS ARE TYPICALLY: THERMAL DAMAGE, SURFACE FINISH, ROUNDNESS, AND CONSTRAINTS ASSOCIATED WITH THE MACHINE TOOL SUCH AS STIFFNESS.

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SCENE 27. CGS: MALKIN 02.21.54 – 02.23.55	**MALKIN:** When we look at optimization, we first have our simulation, and the simulation predicts what's going to happen during the process. By calibrating the simulation to make it more precise, we have a better prediction of what happens during the grinding process. If we change parameters, it's going to tell us what's going to happen. Since we now have a quantitative description of the grinding process, it's now possible to do many different things. First of all, we can do 'what-if' scenarios, what if we change one of the parameters. We can see what would happen if we change the dressing parameters, change the dressing lead. Or if we're doing an internal grinding operation on a 16-mm diameter surface, and we use a 45-mm diameter wheel, what would happen if we increase the wheel diameter to 50 mm. It has a big effect. Sometimes it's an effect that's not realized. We can look at all these things in simulation. We can also look at changing the wheel grade, what happens? We can also look at what's the effect of the machine's inherent ability of the spindle to make round parts. So we can do a trial and error where we try and change the parameters and see if we can increase, by changing the parameters, if we can get a better solution, a process that provides the quality we need but also does it faster.
SCENE 28.	**NARRATION VO:** OPTIMIZATION REQUIRES A PRAGMATIC APPROACH WHEN CONSIDERING THE ACTUAL IMPLEMENTATION ON THE FACTORY FLOOR. IN MOST CASES IT REQUIRES AN UNDERSTANDING OF THE COMPLETE SYSTEM. THIS EXPERIMENTATION INCLUDES SUPPLIER INVOLVEMENT, AND CONTINUOUS IMPROVEMENT TECHNIQUES. WHEN DONE WELL, IT IS NOT UNUSUAL TO REALIZE IMPROVEMENTS OF 50% OR MORE.

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SCENE 29. XIAO 04.56.01 – 04.57.34 Dave, please fill in the missing words.	**XIAO:** Optimization is the word people always used, but I don't believe there is a real global optimization. I treat optimization like continuous improvement. You do optimization at the beginning, which is kind of local optimization. Then you find you can improve it again. So it is continuous improvement during the whole process. It is very important in my mind to have the continuous improvement, to optimize it to the better point. For quantity, specifically, there is a couple different ways to say optimization. The traditional way, the easy way, is to optimize time, which is the least process time, __________ time, and making the minimum. But actually when you ___________ sometimes you see that is not the real issue, you have to minimize the cost. I think the cost is much more important to optimize the process. If you put a huge capital investment in it, even if you do the best cycle time, the overall cost is still high. So I think to use the cost model is a much better concept, plus continuous improvement.
SCENE 30. XIAO 04.57.54 – 59.49 Landis B Roll 05.48.37 – 05.52.11	**XIAO:** When done right, it depends. I'll give you one example. If you look at the results, you should be amazed. This is one example in GM. This is the first cycle the vendor gave to us, which is about 60 seconds per part. So the cost is like $25 for ________ for just the grinding process. We did some optimization approach, and it came out the results was like 26 seconds, and the cost was like $10, which is like 60 or 70 percent improvement. This is very significant. This is not just the cost of _________, if you look at the investment, it's a huge difference. If you do the old cycle, you could use maybe 16 grinders, the cost is maybe $1 million for one. But after that we only need 9, maybe 6 is good enough. It's not just reduce the operational cost, at the same time reduce the capital investment.

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SCENE 31. XIOA 05.05.55 - 08.33	**XIOA:** Most significant in my mind, usually people do optimization after everything is set up, then they do the optimization. That in my mind is kind of the wrong concept. Actually the initial setup is the most important. Choose the wheel, choose the right machine, and then based on this, put the wheel and the machine in the optimization process. They become a variable, not a given condition. If you do that, optimization room is much bigger than you think. Also the coolant plays a big role. I can give you one example in this application. The original wheel is limited cycle is more than 60 seconds, you can't do anything about it. You go very slow or it damages the surface, general cracking, high residual stress, you cannot go any more abrasive, you have to slow down the machine parameter in the optimization theory. After we test some of the grinding, we know what kind of specific energy should be generated by the wheel to satisfy our condition. So we bring the supplier in and tell them, that's the specific energy the wheel has to generate, that is the condition the wheel has to generate. So they go back, they become part of the optimization process, the supplier. They test maybe 12 different wheels, they give us 12 different combinations and we try it. So we choose the one that can significantly reduce the cycle time and the quality is pretty good. And the same thing with the coolant. you choose the right coolant, the dressing interval can enlarge almost 10 times. In that aspect, if you put this initial ________________ optimization theory, when you are learning this in school, it's a given condition. Actually it's a part of the organization, a big part of it. I think right wheel, coolant choice, those are most important. After you select the right one, then you do optimization of the cycle, it's much easier.

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SCENE 32. Landis PFLAGER 05.38.14 – 39.40	**PFLAGER:** Process developing using software models is pretty well developed. It has been going on for 20 years here. It's really useful when you're trying to quote jobs and tell people how the machines are going to run. The most important areas are material removal rates, thermal models to determine thermal damage or lack of it. You want to avoid thermal damage. Specific grinding energy feeds into the thermal model. The primary ones are machine dynamics, for predicting the cycle times, that's very important in cam grinding. Material removal rates are very important when you're working with wheel manufacturers, so they can get the right wheel in there. Thermal models to avoid damaging the parts is important.
SCENE 33.	**NARRATION (VO):** ONE WAY TO REDUCE CYCLE TIME IS TO USE BETTER COOLANT AND IMPROVED COOLANT APPLICATIONS METHODS THAT WILL THEN REMOVE THE HEAT CREATED DURING GRINDING. AS FEED RATES AND WHEEL SPEEDS ARE INCREASED COOLANT APPLICATION BECOMES MORE CRITICAL.
SCENE 34. WEBSTER 01.06.22 – 07.00	**WEBSTER:** Grinding is a very thermally dominated process. For us to have an effective coolant application is very critical. This includes the pressure we apply the coolant at, the flow rates that we apply, and we need to take the heat out of the process. The heat goes into the chip, it goes into part, it goes into the wheel, and it goes into the coolant, and we need to manipulate those ratios. By effective coolant application, we can prevent thermal damage to the work piece, which is critical, and get a good surface finish.

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SCENE 35. WEBSTER 01.17.12 – 18.04	**WEBSTER:** Coolant has a big impact on productivity, surface finish, and surface integrity. For productivity, you can push the process harder without risking thermal damage. You can get the coolant in the process to achieve that. Surface finish can also be improved because less of the chips that are being removed from the material get embedded into the grinding wheel. We call it loading. Loading can cause scratching and re-adhesion back onto the work piece. By having poor cooling, you can also get localized thermal expansion of the work piece, causing a mottled effect on the work piece. The surface integrity is improved because of the cooling, and in many cases the stresses in grinding can be beneficial compressor stresses, very good for fatigue life on things like bearings.
SCENE 36.	**NARRATION (VO):** AS WE START TO UNDERSTAND THE GRINDING PROCESS AND OPTIMIZATION TECHNIQUES THERE IS ONE MORE COMPONENT THAT IS CRITICAL. WE NEED A WAY TO MEASURE THE PROCESS.
SCENE 37. 05.12.48 – 14.48	**XIAO:** Data acquisition and the calibration is actually in the grinding, it’s very crucial in my point of view. Usually the optimization theory developed by university or industry like GM, it’s kind of a general approach. You have some modeling for the process, you have some simulation modeling system. But this is general. For your specific application, it doesn’t fit. So what we did is calibrate them. So you have to collect some data. I think the most practical is power. So you collect power, and in certain condition you are grinding for this combination, you big it is the power, but after power how big it is. So you compare it. Then modify your modeling inside the optimization software. I think for the optimization there are three parts that are very important, calibration, simulation and optimization.

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SCENE 38.	**NARRATION (VO):** DATA GATHERED FROM MACHINE SENSORS CAN HELP VALIDATE EACH SETTING ON THE MACHINE.
SCENE 39. LANDIS, PFLAGER 05.36.51 – 37.53	**PFLAGER:** Typically sensors are not used to sense wheel condition. Normally the cycles are set up so that is not necessary. Wheels nowadays are consistent enough so you don't really need to do that. CBN wheels kind of by definition are a much more consistent than aluminum oxide. The analogy is with aluminum oxide wheels it's like baking a cake, you have lumps of all different things kind of mixed in there together. With CBN you have a much thinner layer, it's only typically 3 millimeters thick. They're much more consistent. Even though they last a lot longer than aluminum oxide, you get a lot more consistency. So that kind of monitoring issue, if you set the process up right, is not really necessary
SCENE 40.	**NARRATION (VO):** MACHINE TOOL BUILDERS AND CUSTOMERS RELY IN LARGE PART ON THEIR SUPPLIERS OF WHEELS AND COOLANT. USING A TEAM APPROACH WILL USUALLY YIELD THE BEST RESULTS.
SCENE 41. Landis HIKES 05.20.25 - 21.43	**HIKES** Depending on the material hardness, surface finish, and other typical grinding variables, we'll work with those wheel suppliers based on our history with them, and their own history, maybe even with other customers, to arrive at the optimum abrasive for a given process. In most cases today machines use CBN wheels due to the long wheel life and ultimately the lower abrasive cost per part, which may not in all cases be strictly a function of the abrasive. It can also be a function of the amount of tool change time necessary to make that abrasive work. In many cases CBN wheels will last months or in some cases years, which greatly reduces the downtime and improves the availability of the machine tool.

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SCENE 42. XIOA 05.26.52 – 27.34	**XIOA** When we do the testing there are 3-4 wheel suppliers there and 2-3 machine makers there and the coolant suppliers all there. It's very good, because when we do the case, we would grind a couple of parts. Then we identify the properties. For example, the specific energy is too high for this wheel and __________ is too hard, then we know what we want, what kind of wheel. Then we do the test on coolant. We know what kind of oil we need, water based or oil based. Then we put this specification to the supplier, and ask do you have it.
SCENE 43. XIOA 05.28.30 – 30.19	**XIOA** But all the optimization on the user side usually depends on the supplier. The problem with that is if I'm a machine maker, I don't want to give you optimal cycle. If I give you this cycle we originally gave to you I can sell you 16 grinders, which is $16 million in sales for them. After we optimize it, 16 becomes 9 or 8. So half the sale is gone. How can you depend on the supplier to optimize for you if they want to sell more machines to you. Same for the wheel and the coolant. So you have to bring them all together, and the end user has to drive things. You work together. Then you can find huge room to improve and actually will eventually benefit all of them, because it's the competitive that wins.
SCENE 44.	**NARRATION, VO:** THE ROLE OF GRINDING WHEELS AND COOLANT ARE AN INTEGRAL AND VERY IMPORTANT OF THE GRINDING PROCESS. THESE SYSTEMS HAVE BEEN ANALYZED AND DEVELOPED INTO THEIR OWN SCIENCE.

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SCENE 45. WEBSTER 01.05.11 – 05.56	**WEBSTER:** The advances in grinding wheels and coolants are really based upon the development of the bond technology of the wheels. We've had CBN and Diamond out for many years, and also the conventional abraders, but improved structures of the grinding wheels that give much more porosity and enable the coolant to be transported through the process, that's very critical. Also the coolants themselves, they have more lubricity. We have fully synthetic coolants now that allow very good cooling, because they're water based, but they have the lubricity, they made up for that. Not quite as good as oil, but they're getting there, and give very good tool life. Obviously maintenance of the coolant is also critical.
SCENE 46.	**NARRATION, VO:** IN RECENT YEARS WHEEL ADVANCEMENT HAS BEEN DRAMATIC.
SCENE 47. LUDWIG 03.19.29 – 20.00	**PREINESBERGER:** It's mind-boggling what the new grinding wheels can do. If you take, for example, a three-quarter four fluid end mill. You have been able, in the past, to grind the fluids, the channels, into the blank at let's say about 2 inches a minute. In the meantime, double or three times the speed is not unfeasible any more.
SCENE 48. WEBSTER 01.13.35 – 13.17	**WEBSTER:** A complete coolant system comprises initially of a filter system and a pump to supply pressure to the nozzles. There may be a chiller in the system to keep the coolant cool, so the heat doesn't build up and make the process unstable. Then you go through the machine with solenoid valves and special plumbing, and then ends up at a manifold where the nozzle is attached. At that point there may be a lot of pressure that has been dropped from the pump all the way through to manifold. Then it's up to the nozzle to accelerate that coolant into a jet and aim it at the right place, at the right pressure, and the right velocity, to cool the process.

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SCENE 49. WEBSTER 01.14.38 – 15.29	**WEBSTER:** The grinding fluid has to enter the grinding zone to be effective. If it hits the grinding wheel and bounces off, it may cool the part after the grinding wheel has gone by, but it may end up causing thermal damage along the way. Pumping the fluid through the grinding zone is much more effective. To do that, you have to look at the position you aim the jet, the pressure that you apply to the coolant, because that relates to its velocity, and that velocity will break through the air barrier that surrounds the grinding wheel. We have to do it at the right flow rate to take the heat, because most of the motor power for the spindle ends up as heat at the process. We also need to keep the grinding wheel clean by flushing the process and removing material from the process back into the filter system.
SCENE 50. 01.07.33 – 08.35	**WEBSTER:** It's a nice idea to remove the coolant from grinding, but because it's such a thermal dominated process, it's very hard to do. There has been a technology called minimum quantity lubrication, MQL, which is becoming very popular in metal cutting, in the milling and turning applications. But you have very large chips being produced, very little energy from the motor produces very big chips. Grinding is lots of little chips, using a lot of energy. So there is a lot of heat. All the energy ends up as heat. So we still need coolant there. And we also need lubricity to stop the tool from wearing. Dry grinding is completely out, apart from tool room applications. We need to apply coolant, but we can minimize it through an effective coolant application. In many cases, at least half the flow rate. We can go down much beyond that with much more controlled coolant application, but we still need some degree of coolant application to keep the process cool and to keep the tool working longer.
SCENE 51.	**NARRATION, (VO):** A WELL DESIGNED NOZZLE IS ONE THAT ALLOWS YOU TO APPLY COOLANT VERY EFFECTIVELY AND PUT IT WHERE YOU WANT IT.

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SCENE 52. WEBSTER 01.18.27 – 19.38	**WEBSTER:** I use coherent jet nozzle technology, which has been taken from fire hoses from the 1950s, and it allows you to get a very laser-like jet into the process and minimizing the coolant. Minimization of coolant is very important because of the environmental concerns associated with coolants. Nozzles, because they are coherent, have to be aimed extremely carefully by the operator. Nozzles I use are also made from metal, so they don't deflect. When you're running at 200-300 psi, we must not deflect the nozzle, and some of the plastic nozzles deflect at 20 psi, which means they are not aiming where the operator originally intends. A nozzle also has to supply the right flow rate, it has to have bends and be able to be adjusted to aim into the process. So it is more than just a nozzle, the manifold and adjustment mechanism that holds the nozzle is also important.
SCENE 53. **WEBSTER 01.21.11 – 22.03**	**WEBSTER:** High pressure systems in grinding application, in coolant, it has various advantages and disadvantages. If you apply a jet far faster than the speed of the grinding wheel, it's going to bounce off, just like if it's going too slow for the grinding wheel. For the main nozzle, I match wheel speed. If you're grinding at 6000 surface feet, you only need a pressure close to 60 psi, you don't need high pressure. But high pressure is very effective in cleaning the grinding wheel through special nozzles running at pressures up to 1000 psi. But we don't use those nozzles and that pressure for the main grinding. It won't be effective. So separate the functions, cooling and cleaning, rather than have a compromise mid pressure that is not going to give you good grinding.

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SCENE 54. WEBSTER 01.24.20 – 01.25.36	**WEBSTER:** Coolant application has given me a valuable tool in improving the productivity of end users and their applications. One particular example was an aerospace part manufacturer who could only use half the machines in the cell because the central system was shut down. It was over foaming and spilling on the floor. So if they had ten machines connected, only five could be run at any one time, obviously compromising their productivity. By going in there with a coherent jet nozzle technology, and minimizing the flow rate to one third of what it was before, but getting much better grinding, it enabled that customer to grind with all ten machines, and to not have to invest half a million dollars in a new central system. That was one example. Another example was a medical grinding end user for hip joints and knee joints, where improving the grinding wheel life significantly, by three times, they saved $2.6 million a year in consumable tool costs, and the downtime of changing those grinding wheels has also been reduced. So they got more productivity, but they also saved through extra tool life.
SCENE 55. Landis HIKES 05.24.33 – 25.29	**HIKES:** We have a very quantified approach initially to the design of the process, based on a number of grinding variables that have been developed empirically over the years. We can select the stock removal rates to address the customer requirements based on their materials and surface finishes. So it is today a very scientific approach as opposed to the historical black art of grinding, which was much more cut and try.
SCENE 56. LANDIS 05.07.29 – 08.33	**HIKES:** When we design a machine for multiple part operations, it requires a lot of consideration up front in the tooling. The fundamental machine mechanisms need to have the ability to accommodate the variables necessary for the multiple operations on the machine. When we look at primarily the part holding mechanisms, that being the head stock, the foot stock, the work support and work rest operations, and the gaging as well. Gaging is tightly integrated into the grinding operations, as it traditionally has been, and we have taken that and expanded it to the point where we now can, in many cases, gage one or two diameters and fully expect the machine is going to be able to hold the micron level tolerances on subsequent grinds on those components.

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SCENE 57.	**NARRATION (VO)** SOFTWARE IS THE INTELLECTUAL PROPERTY THAT CAN DIFFERENTIATE ONE MACHINE TOOL SUPPLIER FROM ANOTHER IN THE GLOBAL MARKET. SOFTWARE INTEGRATION BECOMES THE MAIN COMPONENT THAT IS REQUIRED FOR EASE OF OPERATOR USE AND ALLOWS FOR ADDING FEATURES IN THE FUTURE.
SCENE 58. LANDIS 05.13.17 - 05.14.19	**HIKES:** The big challenge with integrating controls to grinders, which is my background, has traditionally been presenting to the user or operator an interface that he is comfortable with that allows him to make the changes he needs to make, while embedding all the moves, the plunge cycles, in a fairly protected area. We have embedded in our control many feed cycles and many motions that allow us to do the combined sequences of using a gage on a plunge where required, running a spark our grind where required, tracking wheel wear, which is not a trivial issue, especially when we're doing thrust wall grinding and bump grinding and that type of thing. Again, the integration of all the sensors in the machine is critical to knowing when the wheel touches the part, knowing when the wheel cleaned up the part, knowing where the axis was when the gage says we were at size, and all those types of things.

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SCENE 59.	**NARRATION (VO)** IN TOOL AND CUTTER GRINDING, PROCESS DEVELOPMENT AND OPTIMIZATION IS MAINLY THE RESPONSIBILITY OF THE MANUFACTURER WITH SUPPORT PROVIDED BY THE MACHINE TOOL BUILDER. THIS IN DUE IN PART BECAUSE THE MANUFACTURER MANY TIMES DESIGNS A UNIQUE TOOL FOR A PARTICULAR APPLICATION. THIS IS VERY MUCH A CREATIVE PROCESS. HE THEN IS MORE INVOLVED WITH THE DESIGN AND PROGRAMMING FOR THE TOOL. IN THIS CONTEXT, THE PROGRAMMING OF THE MACHINE TO PRODUCE A TOOL BECOMES THE MAJOR AREA OF PROCESS DEVELOPMENT.
SCENE 60. MANLEY 00.37.17 -37.29	**MANLEY:** Our hope would be that we develop a generic abrasive solution and give as much flexibility as we can to the software so that it can accommodate the needs of any individual client within the industry.
SCENE 61. MANLEY 00.35.52 – 36.33	**MANLEY:** It’s always a good question how you develop a process with your client. One thing we always say is we want to have the ability within the machine tool to do whatever you like. We have five axes of motion, so you can virtually process anything you like. We have high horsepower. We have linear drives with phenomenal surface finishes, phenomenal speeds and feeds, phenomenal accuracy. We have high pressure coolant. Really we have everything you need to make whatever you want, whether it’s an automotive component, whether it’s a network envelope, a cutting tool, whatever it might be. So the question is, how do we serve an individual client.

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SCENE 62. MANLEY 00.37.29 -37.59	**MANLEY:** Above and beyond that, there is a very large pool of applications engineers, and now a very flexible software package called Tool Studio. Tool Studio now allows Walters to simulate a tool that a customer wants to make at the head office, be it Germany, or in the United States, or even an applications engineer's office. We can simulate that from a print we've been given by a client, email that to the client, use a simulation wizard
SCENE 63. STAYLOR 03.29.46 – 30.33	**SAYLOR:** I guess one of the bigger advances we have seen is through the newer software and some of the newer systems, we're able to simulate offline what we're doing and what we're working on. We can monitor and track the performance of the machines. Not the actual grinding performance, because that's directly related to grinding wheels and coolant quality and oil purity. There's a huge number of variables that are related to how fast you can grind. But in the simulations we can get relatively close, and we can also tweak at different points of the grind how fast we are going.
SCENE 64. SAYLOR 03.24.50 – 25.26	**SAYLOR:** Grinding, there's science to it, but for the most part the quality is related to what you can see. If you have an eye for the product or what you are trying to make, then you go in and see subtle nuances that other people won't. So a lot of the process, while we're able to set up and produce and have everything ready from the get-go, a lot of our actual process is done by the guys that are doing it. There is a lot of tweaking and correcting details that are actually done by the individual operators.
SCENE 65. MANLEY 00.38.33 – 38.56	**MANLEY:** That tool simulation we've just done, today you could go on the machine and out comes a finished tool, assuming your wheel geometries are correct. This is a big benefit to the end user. It's the cooperation between the machine tool builder, the customer, and of course the end user of the cutting tool.

SCENE 66. MANLEY 00.20.28 – 20.52 Use video provided by Walter titled "Heli-Vision"	**MANLEY:** This is why I see the biggest trend being toward more automated processes, particularly toward automatic loading devices, automatic wheel sticking, automatic process measuring, and also the ability to process different tools in the same batch and smaller batch sizes, yet accumulate 10 to 15 batches in one autoloader.

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SCENE 67. MANLEY 00.21.08 – 21.48 Use video provided by Walter titled "Heli-Vision"	**MANLEY:** Anybody can buy the same Walter Tool and Cutter Grinder, a Vision, with the 300-position loader, with the automatic wheel changer. They can buy a Helicheck measuring machine to automatically inspect the cutting tools, to automatically inspect the wheels. And people are doing it, on every continent, in every country. It's a very simple business model to set up. It's very capital intensive. Hopefully, we're wise business people and we'll utilize our capital at 100% of its capacity.
SCENE 68. Use video provided by Walter titled "Heli-Vision"	**NARRATION (VO)** WALTER'S RICK MARTIN SEES THE SIMILAR REQUIREMENTS. THEY PROVIDE A SOFTWARE TOOL CALLED "TOOL STUDIO" THAT HAS MANY FEATURES THAT HELP WITH PROGRAMMING A NEW TOOL, SETTING UP CYCLES, AND OFF LINE SIMULATION.
SCENE 69. WALTER 04.19.06 – 20.42 Use video provided by Walter titled "Heli-Vision"	**MARTIN:** One thing about Tool Studio software is the ability to set up offline and simulate the actual dimensions offline. Prior generations of software used approximations for the machine geometry, the grinding wheel geometry, and the resulting simulation was in effect a very accurate estimate. Now with the Tool Studio generation, it has the actual grinding wheel dimensions, including the curvature and shapes on the corner of the wheel, the actual machine dimensions, and even the actual cutting tool holder. Hence the simulation is an accurate representation, meaning your setup is accurate.
SCENE 70. WALTER 04.21.04 – 21.04 Use video provided by Walter titled "Heli-Vision"	**MARTIN:** In addition to the abilities of the accurate setup offline, in the past to get very complex geometries, it took a very high programming skill. Now the Tool Studio lets almost a layperson, a lower skilled person to program very complex geometries at their machine or at their PC without having a high level of software capability.

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SCENE 71. WALTER, EHRLICH 04.05.40 – 06.28	**EHRLICH:** Wheel changing and Tool Studio, the wheel changing machine allows us to get into the higher complex tools, or the more complex tools that are in the industry that are normally done in multiple chucking. If you can do the tool in one chucking, that's more the customer can get out with less amount of time. Our Tool Studio software is a software that allows us to do the more complex tools that the customers have introduced into the industry, the multiple helixes, the variable helixes, differential cores, things like that. This software will adapt quite easily to those changes, and be able to shape the market even for the future for tools that haven't even been developed yet. .
SCENE 72.	**NARRATION (VO):** ENVIRONMENTAL CONCERNS AND "GREEN CONCEPTS" ARE ALSO DRIVING THE INDUSTRY.
SCENE 73. LANDIS 05.25.55 – 27.14	**HIKES:** The most obviously environmentally friendly feature of our machines is the enclosure system. We design our machines to comply to the prevailing OSHA standards, as well as international standards of mist emissions. We design our machines so we get no drips on the floor. There is no coolant on the floor, there is no hydraulic oil on the floor. All the sealing systems have been refined over the years to allow us to present a machine that releases nothing to the environment if the machine is maintained in its proper state. We also deal with various coolant types depending on the customer. We see oil coolant as being a trend in some quarters, due to the fact that it lasts virtually forever, thus allowing the customer to have no disposal costs, and the associated benefits of that
SCENE 74. LANDIS 05.27.18 – 27.23	**HIKES:** We have an eye toward energy efficiency in our machines. We work on the bearing designs. Surprisingly, the servo systems we use have also allowed a high degree of energy efficiency.

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SCENE 75.	**NARRATION (VO):** ENVIRONMENTAL CONCERNS ARE IMPORTANT TO THE TOOL AND CUTTER MARKET BECAUSE MUCH OF THE MATERIALS BEING CUT ARE CARBIDE WHICH CAN BE EXTREMELY HAZARDOUS.
SCENE 76. MANLEY 00.33.16 – 33.30	**MANLEY:** I think a bigger question is, as a cutting tool industry we should ask what happens to the carbide we take out of the blank. Carbide, as we know, is a carcinogen, what do you do with it? From a green perspective, what are we doing as an industry? One, we're making machines that are fully enclosed, and virtually leak-proof.
SCENE 77. MANLEY 00.34.16 – 35.32	Two, we're using mist extractors that are basically electrostatic plates that filter down to generally the .05 micron range, typically about 100 times finer, from my understanding, than what the EPA requires. So now you have healthy operators. Then when you go to open the door, there's a slight pause, so you have a net evacuation of air from the machine with the mist extractor, before the operator breathes in that oil. The final equation is, what happens with the actual oil that has swarf contained in it. Today what we're doing is going away from standard paper band filter systems or standard cartridge type filter systems to what's called edge filtration. As a result, we can recycle the carbide now. We can utilize the oil for a life of five or more years. -- FADE TO BLACK --

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SCENE 78.	**NARRATION (V0)** ABBOTT MACHINES A REMANUFACTURER OF BORING MILLS AND CYLINDRICAL ROLL GRINDERS BASED IN ALTON, IL, HAS BEEN WORKING CLOSELY WITH SALZER METCO AND 3M TO DEVELOP A UNIQUE APPLICATION FOR GRINDING HVOF THERMAL SPRAYED COATINGS USING ABRASIVE BELT TECHNOLOGY.
SCENE 79. ELLINGSON 01.35.39 – 35.29	**ELLINGSON:** HVOF stands for high velocity oxygen fuel. It's one of the five processes of metallizing, and it's used for a lot of wear application coatings. It has tremendous use in hard chrome replacement at this time. We're spraying tungsten carbide materials through a flame process. It might be a gas gun, or it could be a gun that's run by liquid fuel. These molten particles are propelled onto a prepared surface, you form a coating, and you can grind finish these or leave them in the sprayed condition if you need to.
SCENE 80. ELLINGSON 01.35.39 – 35.29	**ELLINGSON:** HVOF is used over other types of coatings because, for example, it has extremely high bond strength. It's a very dense coating, less than 1 percent porosity in a lot of the carbide applications. It's tremendously effectively used to replace hard chrome replacement for the fact that **it's a very green process**. You don't have any effluents or chemicals that you have to dispose of. It's a very fast process. You can deposit the coatings very quickly as compared to chrome plate. It also offers better wear resistance than chrome, and better corrosion protection than chrome in a lot of applications.

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SCENE 81. ELLINGSON 01.35.39 – 35.29	**ELLINGSON:** Some of the applications and uses for HVOF coatings, many industries are using coatings. You look at the aircraft industry for coating the jet engine components, wear resistant coatings in those applications. You have petrochemical applications, sucker rod couplings down to plunger type cooling. You have the automotive industry that might be using coatings on valves, and they might use them in other applications such as seats and so forth. You look at the hard chrome replacement application. There you've got applications used in landing gear on jet aircraft. You also have applications in earth moving applications, hydraulic cylinder applications, replacing hard chrome plate there. In the mining industry, definitely. Pulp and paper industry, paper rolls, print rolls, steel mill rolls, again, hard tungsten type coatings on these applications.
SCENE 82.	**NARRATION (VO):** THE HVOF COATINGS CONTAIN A HIGH PERCENTAGE OF CARBIDE WHICH ACCOUNTS FOR THE WEAR RESISTANCE. THE APPLICATIONS CAN INCLUDE LARGE EXPENSIVE PARTS SUCH AS LARGE HYDRAULIC CYLINDERS FOR EARTH MOVING AND MINING EQUIPMENT AND AIR CRAFT LANDING STRUTS. SINCE THE COATINGS CONTAIN A HIGH PERCENTAGE OF CARBIDE PROVIDING WEAR RESISTANCE, IT BECOMES NECESSARY TO USE DIAMOND ABRASIVES IN ORDER TO GRIND EFFICIENTLY. THIS IS COMPOUNDED BY THE FACT THAT MANY OF THE APPLICATIONS REQUIRE VERY LOW MIRROR SURFACE FINISHES OF THREE TO FOUR RA AND STOCK REMOVAL CAN BE AS MUCH AS .040 TO .060 ON RELATIVELY LARGE DIAMETERS.

SCENE 83. ORF 01.45.44 – 46.49 Show pictures of belts: Abbott B Roll 01.31.47 – 01.34.00	**ORF:** There are a variety of different types of abrasives that can be used depending on the type of material that needs to be ground. One of the big advantages to using abrasive belts is that they can quickly be changed for different finish requirements or cut rate requirements, or from material to material on a wheel based grinder. Changing of wheels is somewhat cumbersome and it can take a long time to change the wheel, plus the truing and dressing required to get the part straight again can be considerable. We produce different belts that can be used on hvof coatings, which would be diamond abrasives. Should we be grinding a chrome substrate, we can use other more conventional abrasive materials as well as grinding steel with those types of product. Ceramic belts, aluminum oxide belts, _____ carbide belts are some of the more common mineral types.
SCENE 84. ORF 01.47.44 – 47.43 Show pictures of belts: Abbott B Roll 01.31.47 – 01.34.00	**ORF:** Specific belts that are used for HVOF coating or grinding require diamond abrasives. The development that 3m has brought to the table has included our Trizec technology. Our Trizec technology is a three dimensional or patterned abrasive which has a wearable depth. Unlike conventional abrasives with a single layer of mineral, the Trizec abrasives have a depth of diamond so that you get a very consistent cut and finish from the beginning to the end of the abrasive life, which is considerably longer than a conventional abrasive as well.
SCENE 85. ORF 01.50.36 – 51.53	**ORF:** Abrasive belts are well suited for HVOF coating in the free cutting nature. They tend to cut very quickly in comparison to a comparable diamond wheel. The abrasive belt technology seems as well to reduce the propensity of induction of chatter or other detrimental grinding results. The heat of the grind seems to be quite low.
SCENE 86. ORF 01.51.17 – 52.51	**ORF:** One of the advantages of using Trizec abrasive belts in place of wheels is the ability to replace the belt very quickly and easily from grade to grade. We can start with a coarse grade roughing belt to remove the majority of the material and get the dimensional accuracy. We can then quickly change from a coarse grade belt to a finer grade belt to achieve a fine finish on the carbide surface.

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SCENE 87. ORF 01.54.12 – 55.17	**ORF:** The benefits of the diamond belt technology vs. wheels increase as the complexity of the part, or the fineness or the improvement in the finish increases. With wheel processes, to achieve finer finishes, typically wheels are not changed. A secondary process and super finishing or honing are traditionally used, and that increases the process time. With belts you can change from your coarse grade to a fine grade in a matter of minutes to achieve your finish. The cost of a belt process vs a wheel process is improved in the labor and productivity savings of the overall operations.
SCENE 88.	**NARRATION (VO):** IT IS NOT UNUSUAL THAT THE TIME TO GRIND ONE PART WITH DIAMOND WHEELS MIGHT BE THREE TO FOUR HOURS COMPARED TO THE ABRASIVE BELT PROCESS FOR THE SAME PART WOULD BE TWENTY TO THIRTY MINUTES.
SCENE 89. ABBOTT 02.14.48 – 15.36 SHOW ABBOTT B ROLL OF THE WHEEL CHANGE PROCESS 54.00 – 55.42	**ABBOTT:** At Abbott Machine Company we have tried grinding HVOF several ways, and the only way we have found it could be done is with a diamond wheel, which we found very hard to dress, and it caused a lot of problems as far as time and selection of grits. When we went to the diamond belts, which we got from 3M, everything worked out much better. To change a belt on one of our grinding attachments takes 60-90 seconds, where changing a wheel, even a diamond wheel, could take 30 minutes to an hour. Then if you had to retrue the wheel, it could take hours.
SCENE 90. ABBOTT 02.13.42 – 14.10	**ABBOTT:** With abrasive wheel you’re always fighting chatter on finishes of any kind. You have to grind also using quite a bit of pressure to break a wheel down. But with belts they are very clean cutting, they use very little amperage compared to a conventional cutting wheel.

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SCENE 91. SHOW ABBOTT B ROLL OF THE WHEEL CHANGE PROCESS 54.00 – 55.42	**NARRATION (VO)** SEVERAL YEARS AGO ABBOTT MACHINE DEVELOPED AND REFINED A BELT GRINDING ATTACHMENT THAT CAN BE USED TO RETRO FIT EXISTING MACHINES.
	ABBOTT: In grinding HVOF, we find that with belt grinders attachments work very well, and they are very readily adapted to a customer's machine, or if the customer does not have a cylindrical grinder, we can supply them with one. In most cases we remanufacture them. We will go back with manual controls, or some of our customers want full CNC, completely automatic, which we're able to do. Some grinders a customer wants to use are basically worn out, and we will not just stick a belt grinder attachment on those unless it's capable of getting the geometry we know they need. -- FADE TO BLACK --
SCENE 92.	**NARRATION (V0)** WITH NEW ADVANCES IN GRINDING MACHINE SPEEDS, POWER, SOFTWARE COMBINED WITH GREATER CONCERN FOR THE ENVIRONMENT AND EFFICIENCY, THE ROLE OF THE GRINDING MANUFACTURING ENGINEER IS FOREVER CHANGING.

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WEBSTER 01.27.37 - 01.28.55	**WEBSTER:** THE ROLE OF THE MANUFACTURING ENGINEER WITH RESPECT TO GRINDING IS VERY IMPORTANT. MANY ENGINEERS ARE MULTI-TASKING, AND THEY DON'T OFTEN HAVE GRINDING EXPERTS WITHIN THE FACILITY. YOU HAVE TO BE A JACK OF ALL TRADES. IT'S VERY IMPORTANT TO UNDERSTAND GRINDING. THEY REGARD IT AS A BLACK ART. WHEN YOU START TO UNDERSTAND GRINDING, IT'S VERY DETERMINISTIC, AND YOU CAN CONTROL THE PROCESS. BUT YOU NEED TRAINING TO BE ABLE TO DO THAT, AND MOST PEOPLE DON'T HAVE THAT ABILITY. TRAINING COURSES ARE CRITICAL TO THAT ENGINEER UNDERSTANDING MORE OF THE THEORY BEHIND GRINDING. THEY ALSO NEED TO UNDERSTAND TOOLS THAT ENABLE THEM TO SEE THE PROCESS AND QUANTIFY THE PROCESS. DATA ACQUISITION SYSTEMS, VIBRATION MONITORING EQUIPMENT—TO QUANTITATIVELY DEFINE THE PROCESS AND HOW TO MOVE FORWARD. THE ENGINEER ALSO NEEDS TO DEVELOP PROCESSES THAT ARE VERY PRODUCTIVE AND COST EFFECTIVE.

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SCENE 93.	Manufacturing Insights wishes to thank the following contributors for their assistance in the production of this program: Produced By: The Society Of Manufacturing Engineers Executive Producer: Steven R. Bollinger Producer/Director/Editor: David Rembiesa