Hybrid Manufacturing of Turbine Components

Laser metal deposition (LMD) and adaptive repair for higher precision and shorter production time

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The energy sector and, above all, the aerospace and MRO (maintenance, repair and overhaul) markets, will be growing significantly over the next decades. This will increase the price for Ni-based alloys, super alloys, titanium aluminide (TiAl) and stainless steel enormously. The complexity of part geometry, higher product quality, parts machined to higher precision, shorter production time and a lower reject rate will lead to a new production and process strategy.

Fig. 1 HSTM hybrid machine

In the future, it won't be possible to obtain all the relevant production parameters by using conventional production strategies. Therefore, hybrid manufacturing of complex turbine components, like blades and blisks, is the answer. A hybrid machine center combines high-precision and dynamic 5-axes simultaneous machining, laser metal deposition, in-process measuring, in-process control devices and adaptive milling. The hybrid system can be expanded by a 3D scanning system, a buffer storage, a CMM system and a fully automated part handling system to form an effective, high-end flexible manufacturing system (FMS).

New technologies, like laser powder cladding, will become more and more important, not only to produce new complex parts and geometries which are not possible by conventional manufacturing processes, but also to repair damaged parts.

A new access to efficient manufacturing

Hamuel's hybrid machine HSTM offers adaptive and additive manufacturing in the same machine. The laser cladding head is stored in the tool magazine like all the other tools and can be exchanged like any other tool. Thus, the adding of material is easily integrated into the part process. Work pieces can be repaired and / or enhanced with additional features.

The essential advantage of this new generation of machines is the combination of different manufacturing processes in the same close area. For the first time, such a compact laser cladding head has been built. Using the tool gripper, it can easily be changed from its storage position, the tool magazine, into the machining spindle and back again. Fig. 2 shows a view of the tool magazine where a tool (upper position), a probe (in the middle) and the laser cladding head (lower position) is stored in the HSTM machine.

Compact laser cladding head reduces risk of collisions

All units can be clamped in the milling spindle of the HSTM machine with the same standard interface HSK63A. The spindle is used for milling or as a mounting place for the probe or the laser cladding head. The compact design of the laser cladding head permits its very simple use in the usual area of a standard milling machine.

This very compact design reduces the risk of collisions and has been built for the very flexible usage on a synchronous 5-axes machine. The laser cladding head guides the laser beam, the powder and the protective gas (Fig. 3). In general, any kind of laser welding material can be used. The adequate and exact positioning of material and laser focus keeps the heated area small and thermal deformation a minor factor.

The examination of different test parts shows an excellent quality of the welding area which fulfills the stringent requirements for aerospace parts (Fig. 4).

Exact positioning during the entire process

One of the advantages of this kind of manufacturing is the availability of the accuracy of the 5-axes machine for the positioning and movement of each individual axis, as well for 5-axes simultaneous machining. This naturally applies to the laser cladding process, too.

The welding accuracy is as good as it can be. The work piece itself never changes its position. The laser cladding head is positioned through HSK63A, the tool interface. This configuration allows for highest repeatability. All this guarantees the best quality attainable for your process, down to microns.

In traditional repair operations, for example at a turbine blade, one source of deviations is the clamping of a work piece at another work place. Another, even more significant one, are imperfections at the datum faces. The third source of deviations is to be found in the machining tolerances. And the fourth source are deviations caused by high temperature and stress inside the turbine. With hybrid manufacturing, all this no longer presents a risk for scrapping the work piece, because the part is fixed in the same position at the beginning of the process and remains there until the last operation is completed. This reduces processing time, too. Waiting time for the next process step is eliminated. This permits a lean manufacturing concept without storage between the individual process steps.

Process steps for the repair of a turbine blade

Turbine blades for jet engines are very expensive parts that justify a repair. Jet engines have to be maintained and overhauled at regular intervals. Damaged parts have to be exchanged during that maintenance. Turbine blades are among these critical parts made of very specific materials. They are subject to erosion and partial damage. Wear and damage usually occur in the same areas of the blade, such as the inlet edge or blade tip. If wear is within defined limits, the turbine blade will be repaired. The repair of a turbine blade is a very common process carried out at thousands of turbine blades worldwide every day.

Each blade is an individual. During its service life there are changes caused by temperature and / or mechanical stress. Wear and damage, too, are similar in nature, but very specific for each individual turbine blade.

Such a repair process includes about 13 single process steps with the following main tasks:

- Examination of the part
- Removal of the damaged areas
- Build-up welding by laser cladding
- Rework of that area by milling and polishing

These steps are mostly done in a manual way. Sometimes, the operator is supported by robots and machines, but always only for certain single steps. All this requires a lot of knowhow and professional expertise.

Automated repair with a hybrid machine

An automated process requires an adaptive process chain, because each blade is a specific one. How to put a hybrid machine from Hamuel to its optimum use for such a repair chain? The hybrid machine is equipped with some special features to perform all the steps required in repairing a turbine blade. First, the turbine blade has to be fixed in an appropriate fixture in the machine. Then, the operator selects the program for the type of blade to be repaired. The entire repair sequence is controlled by that program.

The blade is measured in the machine

The equipment allows for the entire process to be carried out in one ma-

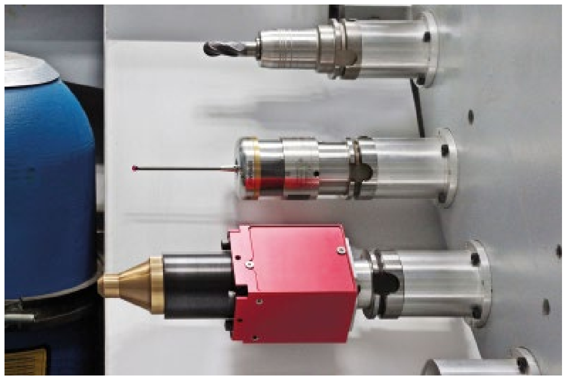

Fig. 2 Tool magazine with laser cladding head, probe and tool

chine. After the damaged turbine blade has been clamped in the HSTM, the component is measured. This can be done with a tactile or optical measuring sensor and captures either the complete component or individual segments. These measurement data are passed automatically from the machine to a connected adaptive CAM system. The original component geometry and the measured actual workpiece geometry in the machine are compared. The adaptive software uses this information to create a modified NC program for the next processing steps.

Defective areas are removed by milling

First, defective portions are removed by milling in order to generate a good surface for the laser deposition welding. Using the laser unit, which replaces the milling tool in the spindle, the missing material is applied on these surfaces. This operation, too, is controlled by the standard CNC of the machine and a standard NC program.

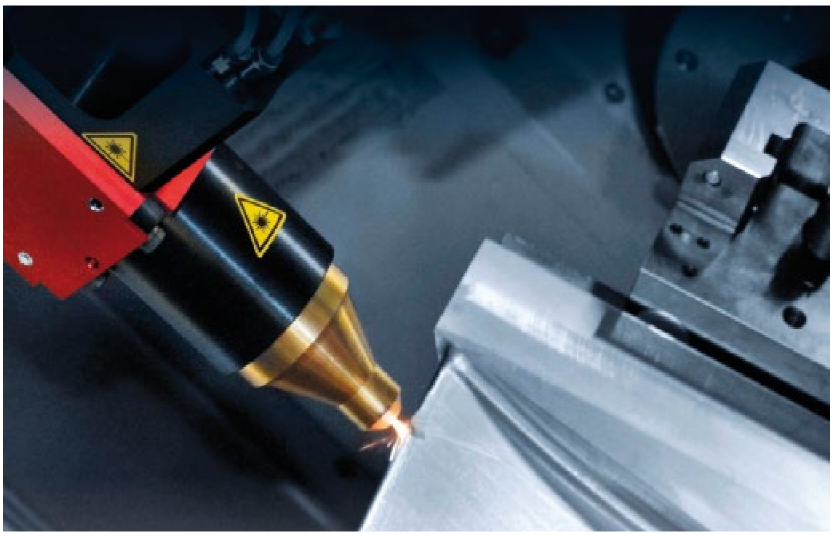

Fig. 3 Laser cladding head in operation on a turbine blade

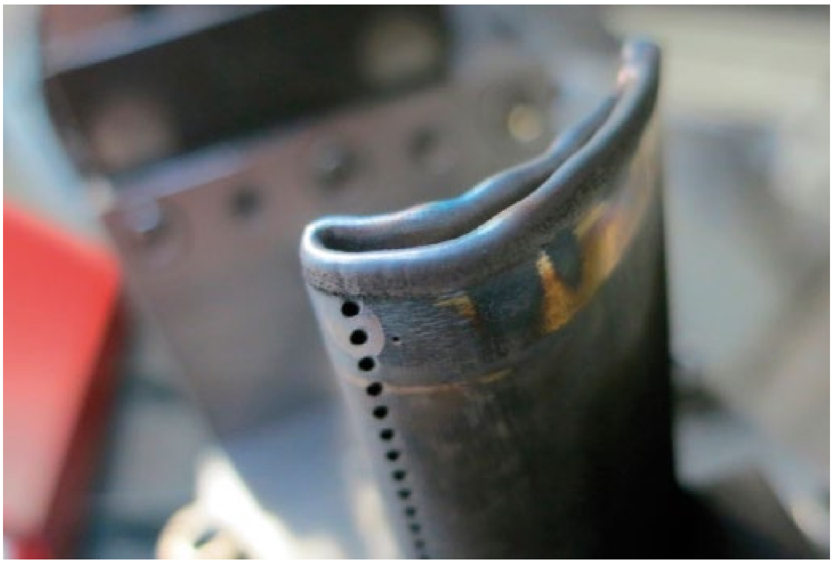

Fig. 4 Example of a welded work piece

The resulting post-weld geometry is measured again. Then, another measuring cycle is started, the measured results are sent to the connected adaptive CAM system, and the milling program for finishing is created from these data to achieve a smooth and stepless transition between the already existing part surface and the material added in the damaged areas. Now, the part is completed. The repaired area can be polished to make it even smoother. For this purpose a polishing tool can be inserted into the standard interface at the milling spindle.

A huge reduction in cycle time can be achieved

The elimination of idle times between the individual machining operations can reduce overall lead time dramatically. The creation of a fully automated process also permits its comprehensive documentation and traceability. Thus, especially for the aviation industry, the required process documentation is ensured and the process repeatability secured.

At present, many process steps are performed manually and cause problems, such as poor repeatability, variations in quality, high reject rates, high rework costs and very high overall costs. All these problems can be eliminated with the HSTM hybrid machine and the automated process.

The HSTM hybrid machine can now cover all sectors of laser machining based on the possibility to use the laser cladding head as a standard tool, which is stored in the machine like all the other tools and is fully integrated into the system.

For example, methods such as laser hardening or component labeling by laser and similar processes are possible. Furthermore, components can be reinforced or enhanced selectively. In areas subject to higher wear additional or more resistant materials can be applied in very thin layers. A possible field of application are gears in transmissions where always similar wear develops, which can be calculated in advance.

Material can be applied in areas subject to high stresses

We are now in the position to apply a different material in specific areas under very high stress to make the component more resistant and more reliable. Here, the work piece does not need to be removed or to be taken to another place or to undergo another process, which has always been a major obstacle for such applications. Thanks to the high position accuracy of the milling machine and the excellent controllability of the laser, these wear-protection and enhanced materials can be applied very specifically and in very thin layers, so that the work piece geometry does not need to be changed to obtain the required strength. Reinforcements or wear protection will

Company

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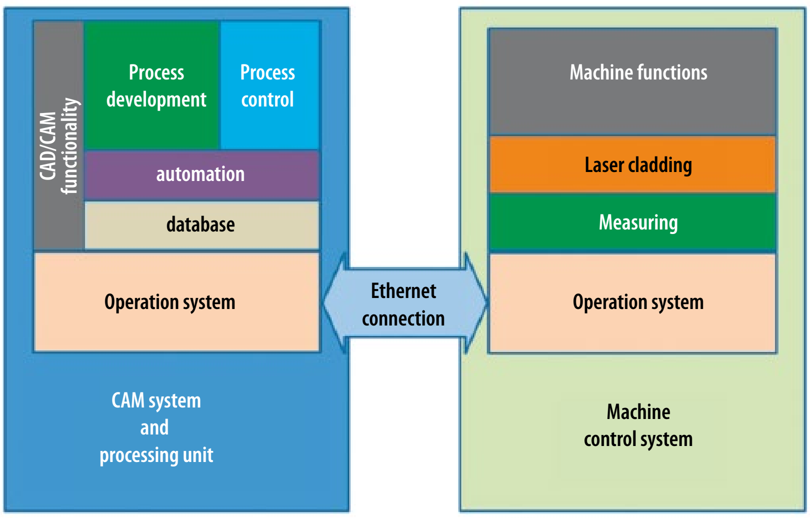

Fig. 5 Relevant software modules overview

specifically be applied in the areas where they are necessary, without changes to the workpiece or the manufacturing process.

It is a novelty for the manufacturers of metal-cutting machine tools to deal with the adding of material. So far, the task had always been to remove the existing material as quickly as possible. This means that for some components, such as turbine blades, sometimes more than 90 % of the raw material had to be removed to get an accurately finished turbine blade. Such machining causes a lot of effort and high costs for material and processing time. As pointed out below, part of this can be avoided if the additive method is used instead.

Hybrid technology allows for saving costs

In addition to the previous machining of a part with flanges (subtractive method), we now also have the possibility of the additive manufacturing of these flanges by build-up welding. In this context, the percentage to be cut away is almost three times as large as the portion you can apply to have the same flange. This explains in an easy way the huge savings potential of the hybrid technology. Radical cuts in processing costs are possible, especially so for expensive materials and materials difficult to machine.

Deposit welding also aims at producing a part with improved technical properties. A wide variety of properties and materials can be combined. The added material, for example, offers surface properties (like wear or corrosion resistance), while the base material has appropriate structural properties (like toughness or a low material price). Thus, the overall work piece characteristics can be improved and influenced very selectively. The added material and the base material have to show a perfect bond.

Compatibility of various materials

The relationship between the base substrate and the added material plays an important part. One of the core points of the process is the compatibility of the various material combinations. Numerous studies of different variations and combinations have been analyzed, so that the process meets even the most stringent criteria of airspace industry at utmost quality.

The characteristics of the connecting areas determine the quality of the bond between the two materials. This will guarantee the final strength of the product. The hybrid system is capable of repairing high-quality metal components, of giving them a second life, instead of using a new part that has to be manufactured. This offers significant cost advantages, especially in high-quality and complex components.

Optimum integration of each step

The HSTM hybrid machine provides the possibility to remove the damaged area by milling off the worn portion, and then rebuild that portion by adding material in a sequence where the component has not to be relocated to other machines to perform the individual process steps. This promises accuracy, repeatability and reproducibility.

Important for the success of such a system is the optimum integration of each step of the entire process chain. The entire process know-how from different partners is available for each area of the process at the HSTM hybrid machine. The adaptive milling software has been implemented together with Delcam. Any other software, like BCT Online, can also be integrated. Hybrid manufacturing technologies have contributed to the development of the laser unit.

DOI: 10.1002/latj.201600013

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