2 State of the art

Stand der Technik

2.1 Laser-based repair processes and CAD/CAM technologies for turbomachinery parts

Laserbasierte Reparaturprozesse und CAD/CAM Technologien für Turbomaschinenteile

Laser metal deposition is an established technology to realize repair process for turbomachinery components. The advantages of LMD technique in repair processes can be summarized as

1. Near-net-shape result, able to build even very small geometric features up to 100-200µm [ATWO98][NOWO07][WUXI03][GASS10];
2. Able to rapid manufacture individual and small volume components since it requires no special tools and customized molds;
3. Less material and resource costs compared to conventional techniques, for example 90–95% of high performance material is machined away to produce integral turbine components [GASS10];
4. Flexible manufacture and repair capabilities [FESS96][GASS10].

These advantages enable LMD technique commonly applied to produce/restore various parts especially for turbine components. However, as introduced in Chapter 1, the turbine parts often bear part-to-part differences of dimensions and shapes. This causes deviation between the nominal CAD model and the real part. On the other hand, precise representation of the real geometry of the part is required for the CAM planning of laser process. This conflict poses a challenge to an automated repair process.

There are some previous studies focusing on automated repair methods for turbine blades using measuring techniques. General Electric developed a series of gas turbine component repair processes that are based on different types of technologies to reduce maintenance costs and enhance equipment availabilities. This report covers repair cases on different areas of gas turbine components, including nozzle, stage two and three blade, rotor and combustor. Failures of parts on these areas are categorized and analyzed, and accordingly various technologies are applied to repair the defects with different sources [PALL01]. For example, an improved weld repair method called Nozzaloy^{TM}, which uses advanced filler material, is applied to deposit a metallurgically stable proprietary alloy combination to the nozzle surface. For repair of high strength bucket alloys, a technology called Weld Repair Advanced Process (WRAP^{TM}), which uses a controlled environment box to regulate heat input and cover gas, has been adapted to improve the conventional wire-based weld repair techniques for industrial gas turbine components. To automate these techniques in industrial repair processes, GE applies an adaptive robot and plasma arc welding devices, in order to solve the accessibility problem of the unique shape and positional variation of some critical areas on turbine components.

Regarding aero-engine and industrial gas turbine's maintenance, repair and overhaul (MRO), BREMER proposed an automated repair approach for repair of blisks. This approach combines adaptive machining methods, as well geometrical adaptation of

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NC paths to the actual part geometry by in-process measuring techniques and mathematical best-fit strategies. A data management system is created to establish virtual MRO workshops, so that the data flow between each individual component can be efficiently transferred among different processes and facilities without loss of information [BREM05].

Gao et al. introduced a 3D non-contact measurement-based repair integration system, and provides a solution to create an individual blade-oriented nominal model to achieve adaptive repair process and automated inspection [GAOJ05]. The same researchers constructed a polygonal model from measured data of real parts and accordingly propose a polygonal-model-based repair strategy to generate correct laser paths for deposition process, and also adaptive machining process to each part through the reverse engineering application based on 3D scanning data [GAOJ06]. In this study, GAO et al. propose a repair system with reverse engineering environment, in which three main steps supported by CAD/CAM tools are established: in the first phase a GOM ATOS II non-contact digitizing system is used to scan the worn parts and acquire a preliminary data of the actual part, and afterwards errors from digitizing process are corrected by resampling of defect patches and repair of holes and gaps, in order to create a defect-free polygonal model; secondly automated alignment is applied to compare the digitized model with scanned data of worn part, and accordingly to eliminate errors and identify repair patches; at last repair profiles are extracted from the repair patches’ geometries to generate repair NC paths.

Flemmer et al. from ILT developed a process chain for LMD using a CAM software module, LACAM3D, which is based on a polygonal modeling approach for geometry representation and calculation [FLEM12]. With this tool the noise of measured data can be reduced by NURBS approximation and geometry model of the worn part is obtained by best fit with nominal CAD data. Several functions are integrated in this software module for the user to edit, manipulate and handle the triangulated surface, with consideration of the specialties of laser process. The characteristic features of process area can be extracted from measured data by these functions with a certain extent of user interference.

Considering the requirements of the turbomachine industry, one will find that the previous research and development studies hardly meet the demand of mass production. Firstly, the defects in the critical areas on parts are randomly distributed on the surface and cause large deviation between the real part and the nominal model, as well as the part-to-part deviations due to the errors from unprecise manufacturing process like casting. Additionally, since the repair area should be prepared by milling process, the after-milling surface is far deviated from the designed model. Therefore, it is not possible to make precise CAM planning for laser deposition process only based on the part’s nominal CAD model. And the approaches from conventional reverse engineering in the work introduced above are not feasible for the repair cases in this research.

In the Fraunhofer-Innovation-Cluster “TurPro” (Integrative Production Techniques for Energy-Efficient Turbomachinery), typical repair process chains realized by a series of consequential processes, devices and their supporting computer-aided technologies are demonstrated in Fig 2-1. In these process chains, 3D laser-

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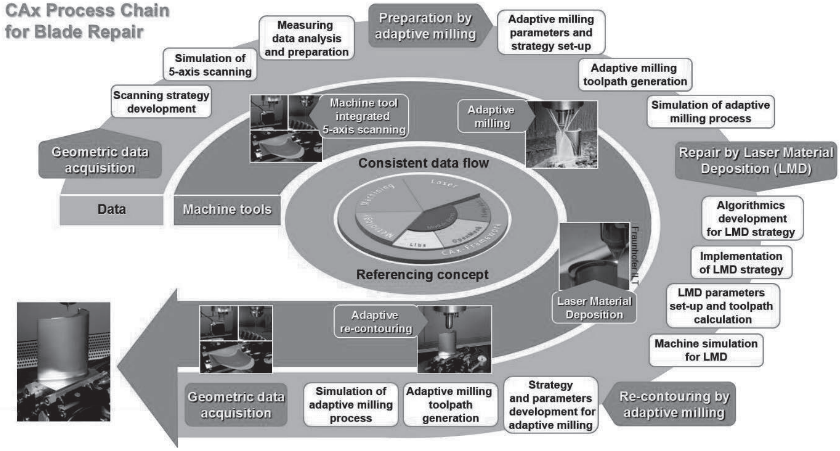

Fig 2-1: Repair Process Chains in the perspectives of hardware and software
Reparaturprozessketten in Bezug auf Hard- und Software

This discrete STL model does not explicitly provides any analytical information or geometric features of the processing area. Typically, in CAM planning of laser paths on a processing area, some segments of the boundary of the area is pre-selected as the basic curves, from which the other laser paths are offset and morphed. So how to extract such feature curves from the STL model of the processing area is the first challenge of the process planning. The difficulty is due to the fact that the existing CAD/CAM tools cannot fully meet the requirements of automated features extraction and generation of NC paths on triangulated surface without manual editing on CAD data and other human interferences.

Secondly, in order to deliver a smooth surface of the deposited material, and also avoid any cavities inside the build-up material, a special pattern of laser paths is required that any two neighboring laser paths should always have equal surface-distance to each other. This requires a special algorithms to calculate interpolation points of laser movements on discrete triangulated faces, which is quite different from the available strategies in the existing CAM software, since most conventional