# Impact of Clamping Technology on Horizontal and Vertical Process Chain Performance

**Roman Kalocsay, Thomas Bergs and Fritz Klocke**

**Abstract** Clamping technology plays a major role in optimization of holistic process chains, determines auxiliary process times, enables process performance and affects workpiece quality. In this study we evaluate three different referencing strategies in horizontal process chains and discuss the effect of fixtures on workpiece dynamics. In order to achieve an optimal process chain performance an optimization of clamping solutions is crucial.

**Keywords** Clamping · Fixture design · Process chains · References · Damping

## Introduction

To achieve robust and economic manufacturing, optimization is not limited to single process steps. A holistic approach must take into account the production process as a whole. It can be structured in two different scopes we call "vertical" and "horizontal process chain". In focus each manufacturing step can be divided into a sequence of tool path planning and machining operations, the "vertical process chain" (Fig. 1). Key factors regarding the optimization of a single operation in "vertical process chains" are machining parameters, tools, tool paths and fixture design amongst others. The "horizontal process chain" addresses the sequence of operations in a larger scope. Horizontal optimization deals with the efficient interconnection of process steps and involves logistics and harmonization of information transfer. Clamping technology can impact both directions of these process chains significantly to improve the overall production process.

R. Kalocsay · T. Bergs · F. Klocke (✉)
Fraunhofer IPT, Steinbachstraße 17, 52074 Aachen, Germany
e-mail: Fritz.Klocke@ipt.fraunhofer.de

B. Denkena (ed.), *New Production Technologies in Aerospace Industry*,
Lecture Notes in Production Engineering, DOI: 10.1007/978-3-319-01964-2_2,

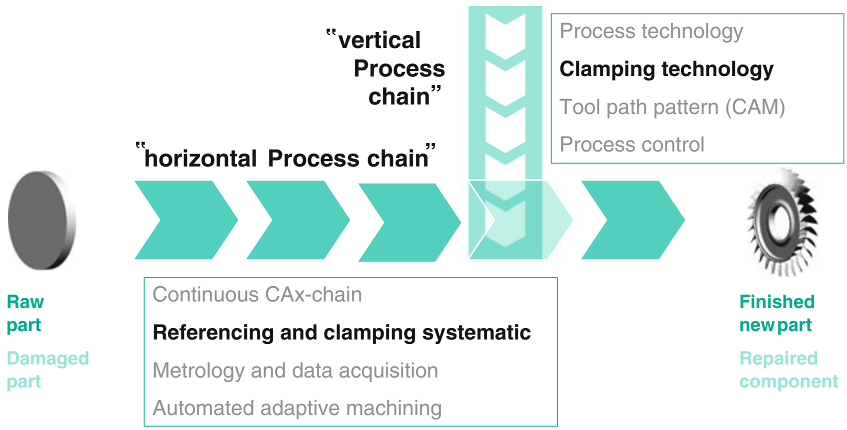


**Fig. 1** Horizontal and vertical process chain

A first design theory on clamping devices was given by [1]. Willy [2] contributed a design method for fixtures in automated industry. In [3] active fixture design is outlined and in [4] a method for setup optimization is presented.

## References and Positioning in Horizontal Process Chains

The performance of horizontal process chains mainly depends on positioning efforts. Optimization therefore requires dealing with references in clamping. Efficiency aims on data consistency, providing a fast way to establish defined relative positions of machine tools and workpieces in each process step. In the following three different approaches are presented (Fig. 2).

### *Clamping Device Based References*

In this approach the workpiece is positioned at a predefined location in the machine tool. In this case movement is purely force driven using spring based, hydraulic or pneumatic kinematics pressing the workpiece onto rigid locators. To overcome jamming caused by friction before reaching the final stop position, the actors engage sequentially with subsequently increasing forces [5] or subsequently in a pulsewise manner maintaining a steady base load. By this means, a high repeat accuracy with usually less than 10 µm positioning tolerance can be achieved, depending on surface quality and friction deviation. In a second step the achieved workpiece position can be stabilized by attachment of additional supports.

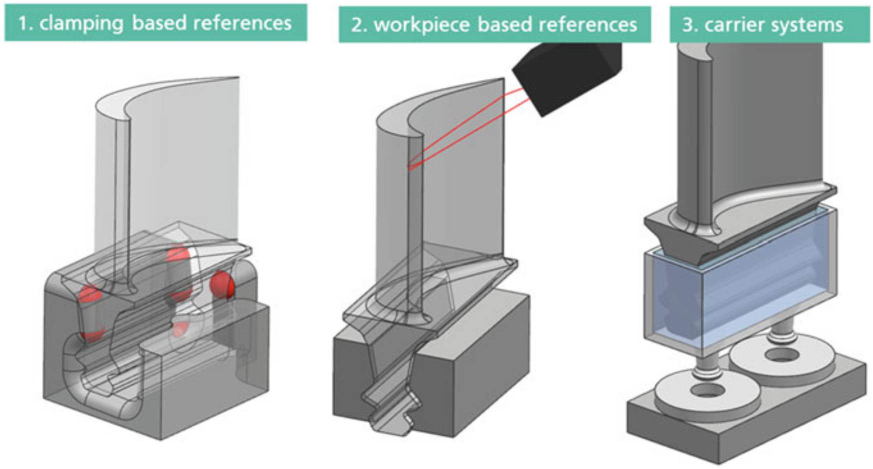


**Fig. 2** Three referencing strategies; *left* clamping based referencing by clearly determined workpiece positioning; *middle* workpiece based referencing using data acquisition; *right* carrier system using cast in workpieces combined with a zero point system

In cast or forged workpieces large deviation of the form causes problems in clamping, especially due to uneven burrs at seams. Because of poor surface quality the classical force-driven positioning approach with rigid locators may lead to such large displacements of the center point that, even with reasonable oversize, geometry of the finished workpiece may exceed the boundary of material at machining position. Consequently, the high scrap rate often needs to be reduced by manual adaption efforts. This can be overcome by a centric positioning approach, which uses rigid kinematics (i.e. centric threads, knee levers or gears). It is crucial to keep the elasticity of the moving parts as low as possible. To enhance stiffness a two-stage approach can be followed: Centric positioning is achieved in the first step. In a second step positions of any moving elements are locked based on friction. Additional stability can be achieved by spring-loaded supports that are locked by friction in a third step. Given that kinematics are clearly determined in the positioning step, a repeat accuracy of <50 µm is achievable, depending on stiffness and bearing play of the kinematics.

In both approaches a high repeat accuracy can be achieved, whereas absolute accuracy of positioning might still be poor. High precision locators for exact positioning are prone to dirt and abrasives. Starting from the resulting natural clamped position of the workpiece and adjusting the machining by performing a calibration procedure offers a more robust and consistent approach. To determine the transfer matrix, the measured position of a reference workpiece relative to the coordinate system of the clamping device is compared with the CAD data being the basis for the CAM programming. The reference workpiece represents the average of the clamped parts, having reference geometry attached.

The main advantage of clamping device based references is time saving as referencing steps for each individual workpiece are dispensable. Combination with zero-point systems for setting up the clamping device provides high flexibility in interchanging machine tools. One possible drawback of fixture based referencing approaches is low flexibility as the design of tailored fixtures and manufacturing a reference workpiece can be laborious. However, in serial production or regarding MRO cases, frequent repetitive clamping tasks are expected to become economically efficient.

### *Workpiece Based References*

In the first machining step reference geometry is applied to the raw part, providing a base for subsequent machining operations. The reference is read out at the beginning of each machining step and machining coordinates are adjusted to each individually fixed position. Usually, the reference is generated by removal of material by drilling holes or milling orthogonal faces. Sometimes metal inserts or optical reflectors are used in fiber-composite parts. In future applications the use of RFID technology appears to be promising for non-metal parts as well. Application of the reference geometry speeds up the time-consuming initial calibration procedure. However, referencing times still accrue in each process step for individual parts. Therefore and to provide an overall efficient horizontal process chain it is important to use a fast referencing method as provided by optical or RFID based systems. Up to now most setups are tactile based, offering robust, cheap and accurate but also very slow solutions.

Difficulties with workpiece based references occur when high material removal rates prevent obtaining a final reference or the reference gets lost during processing. Deviations caused by released residual stress or thermal dilatations of large parts also pose a challenge. The combination of a continuous CAx-chain and optical machine-integrated metrology provides a technical solution here. By acquisition of a 3D model of the clamped workpiece and online comparison with the database in real-time, the coordinate transformation for the machining operation can be calculated without additional reference geometry. This approach also allows adaptive reacting to dilatations and workpiece deformations. However, this requires demanding metrology and CAx programming as well as time consuming scanning procedures.

Workpiece based references enable the use of flexible clamping technology with limited repeat accuracy such as construction set fixtures, vices, magnetic plates, multi piston devices (e.g. Matrix™) or cast in systems without prior positioning steps. Accuracy largely depends on the metrology. The main advantage of this approach is high flexibility, rendering its use in small batch size and being the method of choice for individual production.

### Carrier Systems

In this clamping approach a carrier is attached to the workpiece in the first operation. This not only provides the reference for all subsequent operations, but also constitutes the physical fixation regarding machining forces. The carrier remains attached to the workpiece throughout the horizontal process chain and is removed in the last process step, sometimes followed by an additional step to clean the workpiece. The carrier can be mounted locked by friction (e.g. clamps), form locked (e.g. treads) or bonded (e.g. by glue, castings in bismuth or plastic). Connection of the carrier to the machine is usually provided by zero-point systems, giving the advantage of fast and accurate positioning and high stiffness. Zero-point bolts may directly be mounted into the machined workpiece as well. The repeat accuracy of this approach is equal to zero-point systems (±5 μm); the absolute accuracy depends largely on the first positioning step.

The advantage of this method is the natural preservation of the reference throughout the horizontal process chain. This permits both short positioning times and high precision. The carrier often provides high stiffness and good resistance to process forces and dynamic excitation, especially when bonding connections are used in order to handle complex or thin walled geometries. Drawbacks result from required mounting and dismounting of the carriers. Complex carriers and large process chains can involve high investment costs. Up to now carrier approaches are used in mass production and in cases of very complex workpiece geometry. However, new commercially available zero-point systems with flexible chuck positions open up the opportunity to apply the carrier strategy also to medium production rates and larger production variety.

## Workpiece Dynamics Affecting Vertical Process Chains

Vertical process chain performance depends to a large part on fixture design. The most important aspect is convenient handling, influencing clamping times, scrap rate and process quality. Other important goals in vertical process optimization regarding clamping devices are minimizing operating errors, avoiding unwanted workpiece deformations, shortening setup- and clamping times and lowering fixture costs. In the following workpiece dynamics will be focused on to show the impact of fixtures on process performance.

Stiffness and Eigenmodes depend on the valence of bearings and position of supports. Increasing stiffness enables the use of higher federates with larger process forces if static workpiece deflection limits the process performance. However, regarding workpiece vibrations increasing the damping of clamping devices is more efficient than merely increasing the stiffness. Damping in clamping devices can be obtained by using friction, viscoelastic materials (e.g. low order polymer networks), hydraulic systems and other mechanisms. The use of

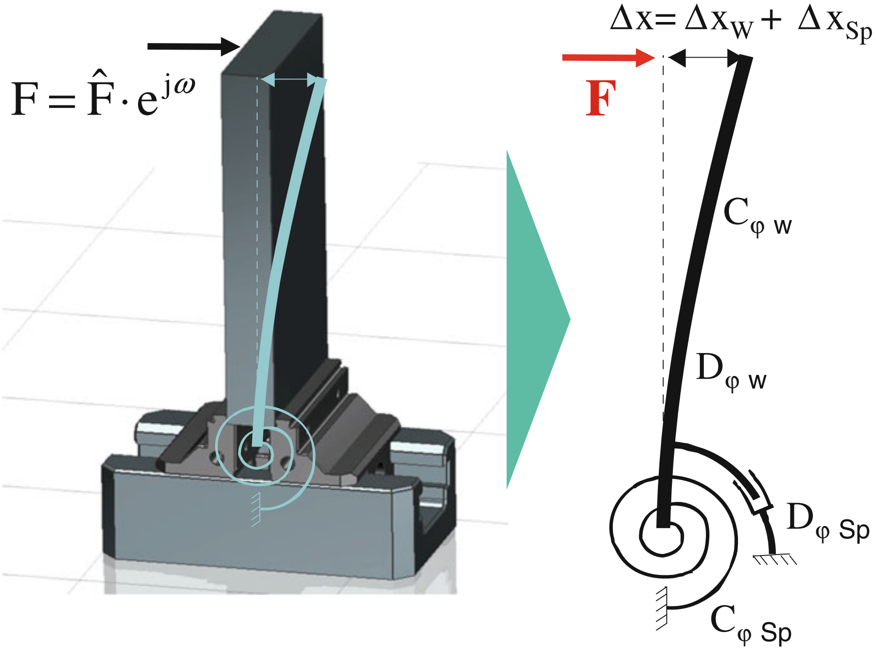


**Fig. 3** Effect of damping in clamping devices. *Left* clamped steel plate 150 × 80 × 20 mm, cantilever plate model of clamping devices. *Right* frequency response, $D_w = 0.1$ %, F = 100 N

HIDAMETS (e.g. CuAl12.3Mn5.l) appears to be especially promising because of its relatively high stiffness, suited to be integrated directly into the flux of forces within the fixture design. Figure 3 shows the potential of damping for a cantilever beam setup. In this simulation the resulting resonance amplitudes can be reduced to less than 1 %, if the clamping device is viscoelastically dampened by 30 %. This value represents the maximum achievable damping ratio using high-dampening metals (HIDAMETS).

Compared to classical fixture design the stiffness of dampening clamping devices needs to be slightly reduced to obtain best dampening effects with lowest amplitudes. In Fig. 4 an exemplary fixture design based on CuAlMn is shown having optimized stiffness properties regarding the clamped workpiece, in this case being a 1.6 m steam turbine blade made of steel with momentum free mount at the tip. A periodical force of 100 N excites in the middle at resonance frequency of 122 Hz. The calculated results show that even with low damping ratios resonance amplitudes can be decreased significantly.

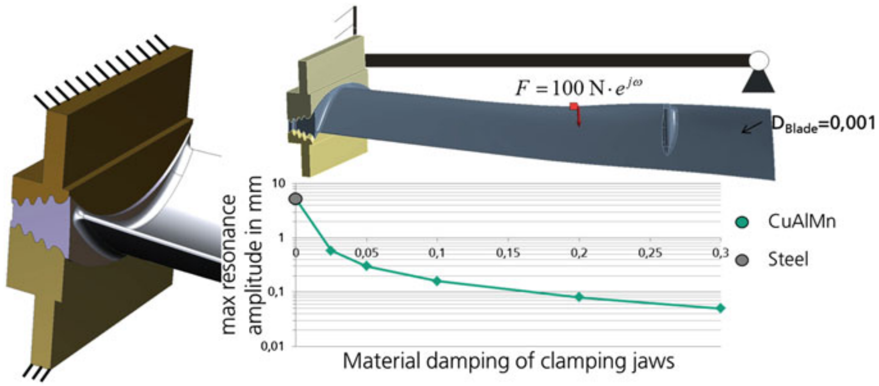


**Fig. 4** Resonance amplitudes versus material damping in a fixture for large steam turbine blades

# Conclusion

In this study we outline the influence of clamping technology on horizontal and vertical process chains with a focus on referencing and also considering workpiece dynamics. Three different approaches of referencing are discussed and the potential of passive damping in clamping devices for optimization is demonstrated. An optimal strategy in clamping needs to consider a variety of factors as pointed out above and requires solutions tailored to the individual production process. In order to achieve optimal clamping solutions an analysis of process chains is crucial.

This publication contains results of the project “DynaMill”, funded by the European Commission within the 7th Framework (FoF.NMP.2012-4).

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New Production Technologies in Aerospace Industry
Proceedings of the 4th Machining Innovations
Conference, Hannover, September 2013
Denkena, B. (Ed.)
2014, IX, 201 p. 131 illus., 95 illus. in color., Hardcover
ISBN: 978-3-319-01963-5