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REAL TIME CONTROL OF CLAMPING IN AN INTELLIGENT FIXTURING SYSTEM

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Abstract: *This paper presents a model-based on-line control of a proposed intelligent fixturing system (IFS). An intelligent fixturing system adaptively adjusts the clamping forces to optimal values during the machining process. It consists of fixturing system, analytical fixture-workpiece stability model, force monitoring module, clamping force optimization algorithm and clamping control system. The emphasis of this research is in the development of adaptive clamping forces control. Numerous simulations and experiments are conducted to confirm the efficiency and stability of proposed IFS. An IFS is suitable for clamping of thin-wall products likely to undergo deformation due to clamping and cutting forces during machining.*

Key words: *intelligent fixture, clamping force control, milling*

1. INTRODUCTION

A fixturing system is used to locate and hold a workpiece in machining, assembly, inspection and other manufacturing operations. The specification of machining fixtures and the application of the clamping forces have largely been experienced-based, requiring the skill of the machinist or manufacturing engineer. Clamping forces are critical to the final part accuracy. At some positions along the tool path, small forces may be adequate, but large forces may be required at others. The minimum clamping forces to secure the workpiece are different as the cutter moves along its intended tool path. An excessive clamping force causes deformation of a workpiece, which leads to dimensional and shape inaccuracy. Insufficient clamping force can permit the part to slip from the locator during the machining process. Especially in cases of machining of thin-walled components, deformation can be minimised by optimizing the location and magnitude of clamping forces. Therefore, in intelligent fixturing system, both the location and magnitude of clamping forces have to be controlled in real time (Hunter et al., 2006). The major disadvantages of such IFS are very high cost and limited accessibility to the workpiece. More realistic and cost-effective approach is to use off-line optimisation of the clamps location and on-line adjustment of clamping force. Monitoring of clamping forces and elements of fixture enables the continuous diagnostic of clamping system. There has been few reported work on techniques to determine optimal clamping forces to be applied during machining process (Deng & Melkote, 2006; Raghu & Melkote, 2004). This paper proposes and presents the development of an intelligent fixturing system that can intelligently control the clamping system during machining. It optimally adjusts the clamping forces as the position and the magnitude of the cutting forces vary during machining. Since adaptive clamping forces appropriate to the dynamic machining environment are provided, the proposed IFS is characterized by on-line monitoring, dynamic clamping forces and real time fixing process control. The ultimate goal is to fully integrate this Intelligent Fixturing System with CNC machines so as to achieve an optimal fixturing and machining process.

2. ARCHITECTURE OF THE IFS

Adjustment of the clamping force during machining requires the control system to be responsive to the change in workpiece dimensions. This is achieved by using a closed loop control using the parameter identification of adaptive control theory. The application of adaptive control theory in this research led to an intelligent fixturing system. The architecture of the system is shown in Figure 1. The structure consists of the fixturing system, fixture stability model, clamping optimization algorithm, clamping control system, force monitoring module and communications with CNC machine tool. At the beginning of the machining process, the workpiece is clamped with an optimal clamping force. Once the machining process begins, the force monitoring module monitors the clamping forces. Once the forces exceed predetermined thresholds, a feedrate reduction request (Cus & Zuperl, 2007) or stop request is sent to the machine tool from the communication module.

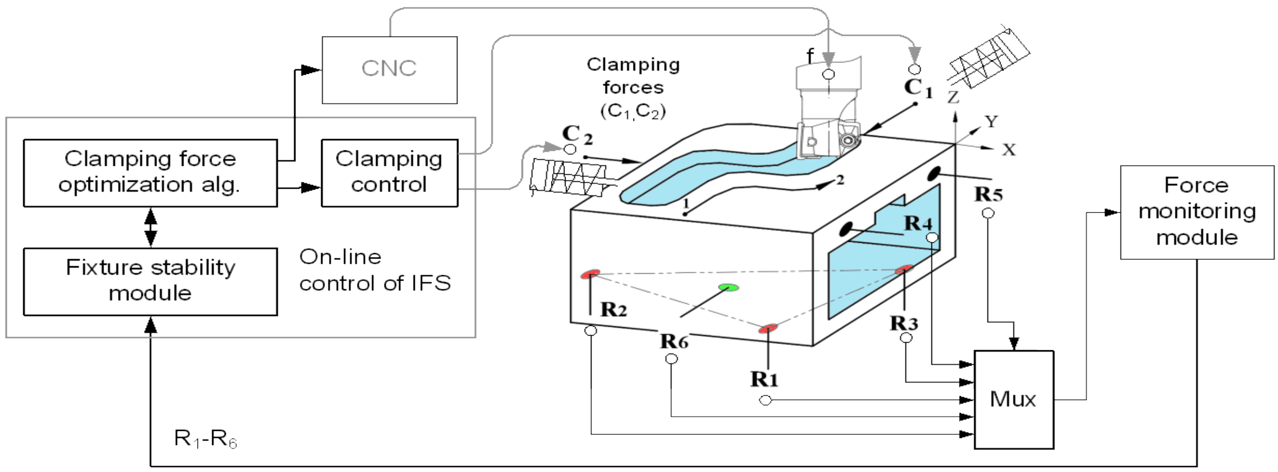

Fig. 1. Layout of IFS control scheme

A reduced clamping force is therefore set and controlled accordingly. The objective of the force optimization algorithm is to minimize all the controllable and reaction forces. This is expressed as the minimization of the sum of the squares of the clamping and reaction forces. Based on the force analysis and rigidity and stability constraints, the algorithm determines the optimal clamping force for every cutter position. The optimal clamping forces are defined as the minimum clamping forces necessary to keep the workpiece in static equilibrium throughout the entire machining process. The predicted optimal clamping forces are then applied in real-time using a hydraulic clamping system. Soft PLC controls a hydraulic system to apply the required clamping forces as the cutter moves to different locations on the workpiece. The clamping forces are proportional to pressure in hydraulic cylinder.

The stability model is used to monitor the fixturing stability during the entire operation. Once instability appears, the module sends a command to the hydraulic system to increase the corresponding clamping force. This process is repeated until the completion of the machining process. Positive reaction forces at the locators ensure that the workpiece maintains contact with all the locators from the beginning of the cut to the end. A negative reaction force at the locator indicates that the workpiece is no longer in contact with the corresponding locators and the fixturing system is considered unstable. This stability criterion has been used by many other researchers (Yeh & Liou, 2000).

3. EXPERIMENTS AND RESULTS

A test rig based on commercially available modular fixturing system has been design to demonstrate the effectiveness of the proposed intelligent fixturing system. Machining experiments are carried out on a thin-wall workpiece. On a Heller Bea 02 machine tool with Fagor CNC controller it is necessary to make the slot shown in Figure 1. Tool path if marked with arrow from point 1 to point 2. The milling cutter of 16 mm diameter with two cutting inserts (R-216-16 03 M-M) with the following cutting conditions: cutting speed (v=25m/min), feedrate (f_z=0.01mm/tooth), cutting depth (a=2.5 mm) is used for the experiment. The workpiece material is the steel Ck-45. Piezoelectric sensors are built into six locators to measure reaction forces (R1-R6) during machining. The measurements indicate that the reaction force R1 at some tool position is almost zero, which means that the workpiece in not in equilibrium. This indicates that the fixturing system is not stable under this set of constant clamping forces (C1=300N C2=250N). The clamping forces must be increased until all the reaction forces become positive.

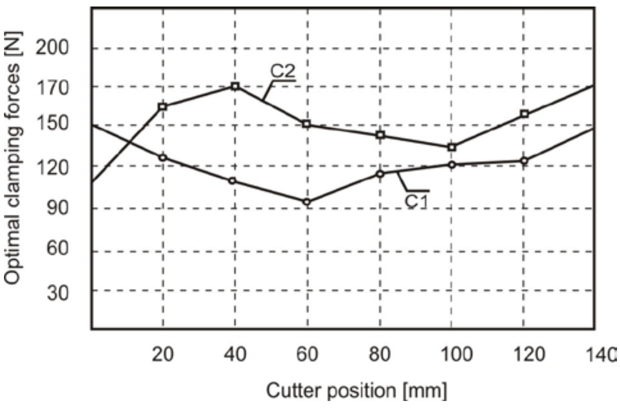

Fig. 2. Optimal clamping forces for all sampled tool-path points

Two hydraulic clamping cylinders are employed to clamp the prismatic workpiece. The fluid pressure in each hydraulic cylinder is measured by a pressure gauge. The cutting forces, tool position, the positions of clamping/locating elements, the friction coefficient (η=0.4) and the workpiece weight (Fg=47N) are taken into consideration during on-line calculations of optimal clamping forces. The optimal clamping forces are shown in Figure 2. Te results show that the clamping forces can be very small by applying varied clamping forces during machining in comparison with fixed clamping scheme. The corresponding positive reaction forces are given in Figure 3 that shows the workpiece will not detach from the six locators.

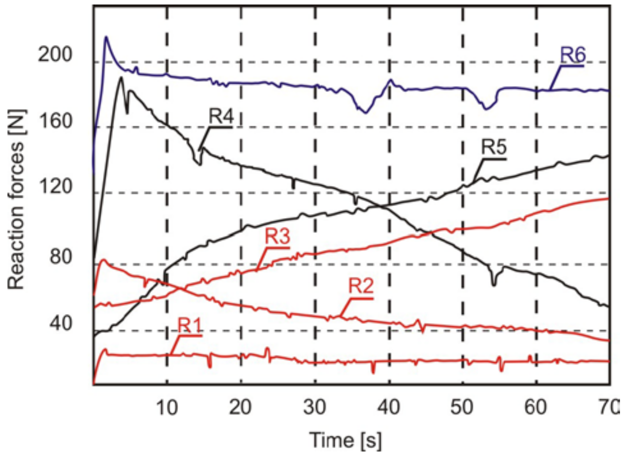

Fig. 3. Reaction forces obtained under the control of IFS

4. CONCLUSION

Architecture and control scheme for a proposed intelligent fixturing system has been presented. This is cost-effective approach which uses off-line optimisation of the clamps location and on-line adjustment of clamping forces.

The sensing and clamping operations of the intelligent fixture are controlled by a PC through Labview application. It is found out that sensor feedback is the most important part of an intelligent system.

The force control performance of the developed system is very promising since the clamping forces can be varied within an interval of 150 msec.

The average accuracy of the machined workpiece is improved for 12% due to adaptive control of the clamping forces and the robustness of the system to disturbances is also greater.

It is expected that future implementation of the system will incorporate besides adaptive clamping force control also re-positioning of the clamping elements.

5. REFERENCES

Cus, F. & Zuperl, U. (2007). Adaptive self-learning controller design for feedrate maximization of machining process. *Adv. Produc. Engineer. Manag.*, Vol. 2, No. 1, 18-27

Deng, H. & Melkote, S. N. (2006). Determination of minimum clamping forces for dynamically stable fixturing. *International Journal of Machine Tools and Manufacture*, Vol. 46, 847-857

Hunter, R.; Rios, J.; Perez, J. M. & Vizan, A. (2006). A functional approach for the formalization of the fixture design process. *International Journal of Machine Tools and Manufacture*, Vol. 46, 683-697

Raghu, A. & Melkote, S. N. (2004). Analysis of the effects of fixture clamping sequence on part location errors. *International Journal of Ma-chine Tools and Manufacture*, Vol. 44, 373-382

Yeh, J. H. & Liou, F. W. (2000). Clamping Fault Detection in a Fixturing System. *Journal of Manufacturing Processes*, Vol. 2, 194-202