Arch-type Reconfigurable Machine Tool

Jaspreet S. Dhupia, A. Galip Ulsoy and Yoram Koren

University of Michigan, Ann Arbor, MI 48109-2125, USA
Email: [jdhupia, ulsoy, ykoren]@umich.edu

Abstract
The arch-type reconfigurable machine tool (RMT) is a full-scale reconfigurable machine tool, designed to provide customised flexibility in milling and drilling operations for a part family, i.e. V6 and V8 engine cylinder heads. The designed machine not only has to achieve the required kinematic task, but should also exhibit similar dynamic characteristic across all members of the part family to ensure specified productivity and quality levels in the manufacturing environment. This chapter begins with a brief introduction to reconfigurable manufacturing systems and reconfigurable machine tools, and later delves into the various RMT design considerations e.g. part family, machine specifications, workspace, and accuracy. The detailed design and construction of the arch-type RMT is described. This section also describes the research activities carried in the area of RMT design. The later part of this chapter discusses the variations in dynamic performance of the arch-type RMT across the various reconfiguration positions. The dynamic performance of the arch-type RMT is measured in terms of frequency response functions and stability lobe diagrams. It is observed, that for the arch-type RMT, the dynamic characteristics are similar across the part family, because the dominant frequency where chatter occurs comes from the tool-tool holder-spindle assembly. The machine dynamics is similar to many other industrial machines used for milling and drilling operations on similar sized workpiece, which are not designed to be reconfigurable. Thus, the arch-type RMT successfully demonstrates the concept of reconfiguration and its application in the machine tool industry.

9.1 Introduction

Traditional manufacturing systems can be classified either as: a) dedicated manufacturing systems (DMSs), where the process is built around a specific part, or as b) flexible manufacturing systems (FMSs), where a process is designed to accommodate a large variety of parts that may not have been specified at the design stage [9.1]. While DMS is commonly used in machining lines and is economical for high production rates, they cannot be easily converted to produce new products. Thus, they are not responsive to changing product demands. On the other hand, FMS consists of multiple computerised numerically controlled (CNC) machines integrated with a material handling system. This allows for a variety of operations at each machining centre and, therefore, the system may produce a large range of
different products. However, FMS can handle relatively smaller capacity, are expensive and industrial surveys [9.2] have shown that their flexibility is often underutilised over their life cycle. Also, FMS lacks the efficiency and robustness compared to a DMS and wasted resources makes FMS uneconomical for many production situations.

The reconfigurable manufacturing system (RMS) [9.3][9.4] is a new concept that bridges the gap between the DMS and FMS, by aiming to provide just enough flexibility (i.e. functionality) to produce an entire part family. It is designed to grow and change within the scope of its lifetime to respond to market changes relatively quickly. Thus, the aim of RMS is to achieve exactly the capacity and functionality needed, exactly when needed. For a manufacturing system to be readily reconfigurable, the system must possess certain key characteristics. These include [9.5]:

1. **Modularity**: Design all system components, both software and hardware to be modular;
2. **Integrability**: Design system and component for both ready integration and future introduction of new technology;
3. **Convertibility**: Allow quick changeover between existing products and quick system adaptability for future products;
4. **Diagnosability**: Identify quickly the sources of quality and reliability problems that occur in large systems;
5. **Customisation**: Design the system capability and flexibility (hardware and controls) to match the application (product family); and
6. **Scalability**: Design the system to allow addition or removal of elements that increase productivity or efficiency of operation.

The more of these characteristics that a manufacturing system possesses, the more reconfigurable it becomes.

While a 3-axis CNC machine may be the basic module for reconfiguration for many manufacturing systems, Reconfigurable machine tools (RMTs) can bring the principle of reconfiguration to the component level for a manufacturing system [9.6][9.7]. The Arch-Type Reconfigurable Machine Tool developed by the Engineering Research Centre for Reconfigurable Manufacturing Systems (ERC/RMS) is such an RMT. This conceptual machine built to demonstrate the principles of reconfigurability and customised flexibility is the world’s first full-scale RMT. The purpose of this chapter is to describe the arch-type RMT, first demonstrated at the 2002 International Manufacturing Technology Show in Chicago. Since RMTs must be designed around a part family, the design and construction of such machines is more challenging than dedicated machine tools or flexible machine tools. This chapter describes the various research challenges encountered while designing such machine tools. The research challenges include choosing the appropriate modules from a library of modules to achieve the kinematic task, finding the errors associated with a particular machine configuration and variation in dynamic performance characteristics of the machine tool across different members of the part family. The next section covers the research carried out in each of these directions and several other such challenges that become prominent when designing RMTs.