CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In previous chapters, the introduction and literature of Electromagnetic Actuator (EMA) system were reviewed. This chapter starts by highlights the EMA system design analysis. The geometry of the actuator was designed using magnetic circuit analysis (MCA), generalized machine theory (GMT) and finite element analysis (FEA). Next, it continued with systematic procedures and details about experimental and finite element analysis (FEA) for structural evaluation processes of modal testing in milling machine. The experiments were conducted under static and dynamic condition. The experimental and FEA results were presented and discussed in next chapter.

3.2 ELECTROMAGNETIC ACTUATOR DESIGN

In this study, the objective for the actuator design was focused on creating the required 10 N force amplitudes. This had enabled accurate frequency response functions (FRFs) measurement for a representative range of machine tools. It was noted that the EMA was designed for use along with ferromagnetic tool materials as these can provide an ideal path for magnetic flux. The EMA was designed to produce controllable force profiles to tool blanks mounted in the tool holder of a conventional milling machine. Current one root mean square (rms) and voltage that was supplied to the core windings had created magnetic flux through the actuator core and across the air gap. When the tool was positioned in the gap, a magnetic attractive and reluctance force was developed in proportion to the core flux. This reluctance force provided controllable yet non-
contacting excitation to achieve one kHz frequency range. Besides, this generation of prototype utilized a solid ferromagnetic core similar in performance characteristic to the first generation EMA prototype (Caulfield, F.D., 2002).

An E-frame core was selected because of its potential to have higher electromagnetic force compared to the C types that were previously used by other researchers (Sodano, H.A., 2006; Rantatalo, M., 2006; Tatar, K. et al., 2007). A single winding was wrapped around each layer of laminated electrical soft steel core. The initial design started with considering the E-frame electromagnet core with a rectangular cross-section as shown in Figure 3.1. A rectangular cross section was chosen because of the shape that can minimize the flux leakage while the straight section provided sufficient length for coil windings. In addition, Esterling, D. et al. (2003) also found that the criteria used to evaluate candidate core design were maximization of electromagnetic force on cutting tool, maximization of stable magnetic flux and minimization of overall actuator size.

Figure 3.1: Electromagnetic Actuator Profile
In Figure 3.1, when a high current signal was applied to the coil, a controllable and stable magnetic flux was found in the core and air gap. Thus, when the cutting tool was placed on this air gap, the magnetic flux created a controllable force that can be used for FRF excitation (Caulfield, F.D., 2002). Based on the criteria in evaluating candidate core design stated earlier, the main consideration of EMA was the maximization of the magnetic flux in the air gap between the poles and cutting tool.

The core of an electromagnet must be constructed of a highly permeable material that was able to conduct magnetic flux. M-19 laminated electrical steel was an excellent choice for this application. The laminated electrical steel helped to minimize the magnetic skin effect known as eddy current losses in the core. Eddy currents were caused by time-varying magnetic fields in electrically conductive materials (Bae, J.S. et al., 2009). It has created heat and associated power losses in the core with focus on the outer surface of the conductor. According to the formula of average power loss per unit volume, it showed that eddy current power losses are proportional to excitation frequency, magnetic flux density and lastly square value of the lamination thickness (Slemon, G.R., 1966). Electrical steel has a relative magnetic permeability approximately four orders of magnitude higher than air. Hence, most of the magnetic flux produced in the coils was contained within the core. Furthermore, tool materials also have high relative permeability which was three to four orders of magnitude higher than air. Therefore, flux flowing through the core strongly favored a path through the tool. When it was inserted into the pole air gap, the air gap created the only significant reluctance to the magnetic flux in the actuator.

The target bandwidth for the EMA was therefore in range of 1000 Hz and the swept-sine excitation signal was predicted to sweep from 0 Hz to 1000 Hz. Other requirements for the EMA included manufacturing considerations, namely the ease and cost of manufacturing the actuator and the size of the unit. The EMA has several parts that required machining or forming. These included the actuator core, its mounting base and its cover. These components must fit together in a package that can be easily clamped into the workpiece holder of any standard milling machine. Design specifications for the EMA were summarized in Table 3.1.