CHAPTER 3

PARTIALLY LAMINATED PIEZOELECTRIC ACUTATOR PATTERNS

In the previous chapter, the actuation force and moment induced by a piezoelectric patch have been analyzed. Subsequently, in this chapter, the total forced response of the arc stator system bonded with a number of piezoelectric actuators at various locations can be determined by superposing the responses induced by respective actuator patches based on the principle of superposition. The objective of this research is to investigate the response of the arc stator system driven by different actuator patterns. Hence, patterns of partially laminated piezoelectric actuators are discussed next.

3.1. PARTIALLY LAMINATED PIEZOELECTRIC ACUTATOR PATTERNS

This study focuses on driving actions of the partially laminated piezoelectric arc stator with different actuator patterns defined by the same size and number of actuator patches based on the segmentation technique [18]. The pattern and number of the actuators affect modal control forces and moments depended on location and size of the actuator as previously reported [9]. In this study, the number and size of the actuator patches are the same for both actuator patterns in order to investigate the system response at the same amount of excitations. There are two different patterns or configurations of piezoelectric actuators. One is partially laminated in the middle of the arc stator span (Figure 3.1); the other is partially laminated near the supports (Figure 3.2). Each pattern has three pairs respectively bounded on the top and bottom surfaces and a total of six actuator patches. Location shift of actuators between the top and bottom surfaces is a half of actuator length. Traveling wave generated by modal vibrations depends on the actuator size, location and patterns. In this case, the size of the actuator patch is designed according to the nodal line of the 9^{th} mode. However, the operating frequency is not necessary to be the 9^{th} mode because effects of actuation forces are partially cancelled out due to the location shift of actuator patches on the top and bottom surfaces. Thus, the total actuation effect may generate the traveling wave at other frequencies, as demonstrated in later studies. Effect of actuator locations on the traveling wave responses is investigated.

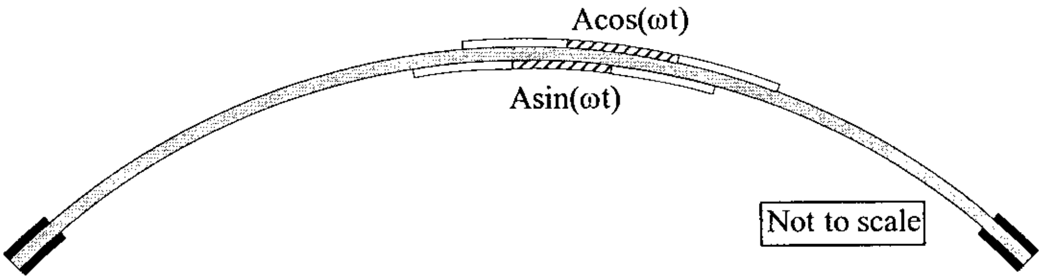

Figure 3.1. The partially laminated arc stator with piezoelectric actuators in the middle of the arc span (Pattern 1). (▭:Steel; ■:Damping material; ▭:PZT + polarity; ▨:PZT – polarity.)

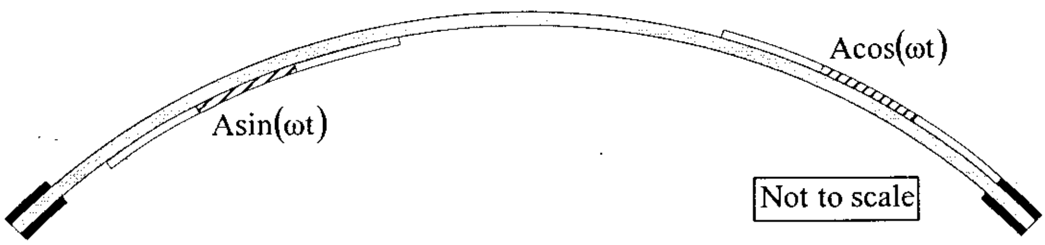

Figure 3.2. The partially laminated arc stator with piezoelectric actuators near the supports (Pattern 2). (▭:Steel; ■:Damping material; ▭:PZT + polarity; ▨:PZT – polarity.)

For both actuator patterns, the top and bottom groups of piezoelectric actuators are respectively excited by a pair of electrical signals: Acos(ωt) and Asin(ωt) where A is the signal amplitude and ω is the driving frequency. In this case, dimensions of the arc stator are arc radius R = 60 mm, arc width b = 9 mm, arc thickness h = 1 mm, arc open angle ϕ_o = π/2, and piezoelectric Lead Zirconate-Titanate (PZT-4) actuator thickness h^a = 0.5 mm. Other material properties of the arc stator, piezoelectric actuator and damping material are summarized in Table 3.1.

Table 3.1. Material Properties.

	Lead Zirconate Titanate PZT-4 Actuator [22]	*Steel Circular Arc*	*Silicon Rubber Damping Material*	Unit
Young's modulus	80 (Y_p)	210 (Y_{stator})	4.2×10^{-3} (Y_d)	GPa
Density	7550 (ρ_p)	7860 (ρ_{stator})	1510 (ρ_d)	Kg/m^3
Poisson's ratio	0.34 (μ_p)	0.27 (μ_{stator})	0.45 (μ_d)	
Damping coefficient	-	-	0.002	
Piezoelectric constant				
e_{33}	15.1	-	-	C/m^2
e_{31}	-5.2	-	-	C/m^2
e_{15}	12.7	-	-	C/m^2
Permittivity	1.15×10^{-8} (ε_{33})	-	-	F/m

3.2. FINITE ELEMENT MODEL

A FE software (ANSYS) is used to model the piezoelectric curvilinear arc driver and to evaluate the system responses in case studies. In this FE analysis, influence of piezoelectric actuator to the system dynamics is taken into consideration. The stator system model consists of a steel circular arc (i.e. the stator structure), piezoelectric actuator patches and damping materials. It is assumed that there is no in-plane deflection in the y-direction. Hence, the system is simplified to a 2D problem. In ANSYS, PLANE13 element type is used to simulate the coupled-field (electromechanical) effect of piezoelectric material. The elements and nodal coordinates of the FE model are rotated parallel to local cylindrical coordinate.

There are two types of boundary conditions evaluated in ANSYS analyses. One is the simply support boundary condition. However, in practice, it is difficult to implement ideal simply support boundary conditions. Hence, a second type boundary condition, i.e. the modified-simply support boundary condition, is considered to mimic the experimental boundary condition. The modified-simply support boundary condition consists of (1) nodal displacements of boundary nodes at ϕ=0 and π/2 in the ϕ-direction are zero and (2) nodal displacements of stator's mid-span at ϕ=0 and π/2 in the 3-direction are zero. Furthermore, the sinusoidal electrical excitations with amplitude of 10V are applied on the surface nodes of piezoelectric actuators. Dimensions of the circular arc are arc radius R = 60 mm, arc width b = 9 mm, arc thickness h = 1 mm, arc angle $\phi_o = \pi/2$, and piezoelectric lead zirconate-titanate (PZT-4) actuator thickness h^a= 5 mm. Other material properties of the circular arc stator, piezoelectric actuator and damping material are summarized in Table 3.1.

In the following chapter, free vibrations of the two patterns of partially laminated piezoelectric arc stator are reported. Then, the system harmonic response is investigated, followed by the total forced response of the motor system. Analytical results of the traveling wave response are compared with the FE results to confirm the motor system behavior. In addition, the wave propagation is also observed to determine the operating frequency.