CHAPTER 1

RESEARCH INTRODUCTION

1.1.ชื่อโครงการ (PROJECT TITLE)

(ภาษาไทย) : รูปแบบการจัดวางตัวทำงานเพียโซอิเล็กทริกและการเคลื่อนที่ของคลื่นในมอเตอร์อัลตราโซนิคแบบเชิงเส้นโค้ง

(ภาษาอังกฤษ) : PIEZOELECTRIC ACTUATOR PATTERNS AND WAVE PROPAGATION IN ULTRASONIC PIEZOELECTRIC CURVILINEAR MOTORS

1.2.RESEARCH AREA: ULTRASONIC PIEZOELECTRIC CURVILINEAR MOTOR

1.3.IMPORTANCE AND MOTIVATION OF THE RESEARCH

A structronic system synergistically integrates electronics, sensor/actuator, control, and structures, which is a structural application of the mechatronic systems. Structronic systems are used in many applications: adaptive wings, sensors or actuators in vibration control systems, variable-geometry structures, MEMS, etc. An ultrasonic piezoelectric motor is also one of structronic actuator applications.

There are many advantages of the ultrasonic motor over the traditional (electromagnetic) motor such as producing a high torque at a low speed with a high efficiency; the high torque produced as compared with its weight - since the inertia of the moving part can be made very small, the position control characteristic at start and stop is well controlled (Toyama et al., 1995 and 1996). There is no need for gears since the large torque can be produced. Precise positioning is possible because there is no error due to the gear backlash. The existing position can be maintained even when the electrical power supply is cut off because of the frictional force between contact areas. It has silent operation since speed-reduction gears are not required (Ueha, et al, 1993; Uchino, 1998) and it has no magnetic field (Hemsel and Wallaschek 2000). For these reasons, the ultrasonic motors are attractive for many industrial or special applications, for example, robot actuators, drive mechanism for auto-focus lenses, precise positioning devices, miniaturized machines, actuators for space applications, material conveyors (Ueha, et al., 1993).

The traveling wave generated at the stator of the ultrasonic motor driving the rotor is a key design factor governing the overall motor performance. (Note that the traveling wave is also often referred to as the propagating wave.) Unlike vibration in ultrasonic piezoelectric circular disk motors (Sashida and Kenjo, 1993; Ueha et al. 1993), boundary conditions of the finite length media (such as beam, plate and arc) reflect the waves when those generated waves hit the boundaries. This may generate undesirable standing waves.

Study of piezoelectric actuator patterns generating traveling waves on the curvilinear motor (finite length media) is a crucial issue for design and development to improve performance of the precision motors. Moreover, it has never been systematically studied before. The methodology and knowledge of this study can be applied to generate traveling waves in other finite length media which will be attractive for many applications, e.g., drive mechanism, micro positioning, wave transport, material conveyer and movable structure.

1.4. OBJECTIVES OF THE RESEARCH

The objectives of this research can be summarized as follows:

1) To study characteristics of the piezoelectric actuator patterns on the ultrasonic piezoelectric curvilinear arc motors.
2) To study wave propagation design parameters of the actuator pattern.
3) To analyze and determine the best piezoelectric actuator pattern yielding stable traveling waves on the curvilinear arc motors.

1.5. LITERATURE REVIEW

Piezoelectric ultrasonic motors have been continuously developed over a decade (Sashida and Kenjo, 1993; Ueha, et al, 1993). The principle of ultrasonic motors is to utilize ultrasonic oscillations (or waves) generated by piezoelectric actuators to create forces driving the rotor by friction at the contact surface as illustrated in Figure 1.1. Most of ultrasonic vibration sources are based on piezoelectric materials bonded with the motor structure.

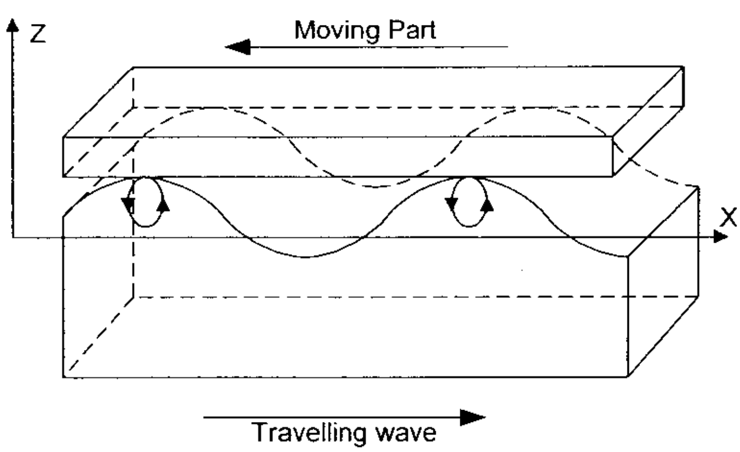

Figure 1.1. Principle of propagating-wave type motor.

An ultrasonic motor system usually consists of a stator and a rotor. The traveling wave generated at the stator driving the rotor is a key design factor governing the overall motor performance (Note that the traveling wave is also often referred to as the propagating wave). Unlike vibration in ultrasonic piezoelectric circular disk motors (Sashida and Kenjo, 1993; Ueha et al. 1993), boundary conditions of the circular arc (finite length) reflect the waves when those generated waves hit the boundaries. This may generate undesirable standing waves. There are techniques to generate traveling waves in finite length media. One technique is to use two actuators with one vibrator at one end to generate the vibrations and one absorber at the other end to absorb those vibrations as shown in Figure 1.2 (Kuribayashi et al., 1985). This technique generates only one-way traveling waves.

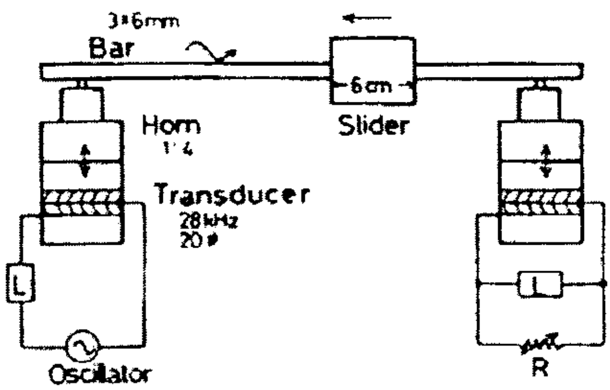

Figure 1.2. Ultrasonic linear motor using two transducers (Kuribayashi et al., 1985).

Another technique is to use two vibrators at the opposite ends generating traveling waves by superposing two standing waves with different phases as shown in Figure 1.3 (Higuchi, 1995). This technique is capable of generating either forward or backward traveling waves by the pair of vibrators operating in the appropriate phases.

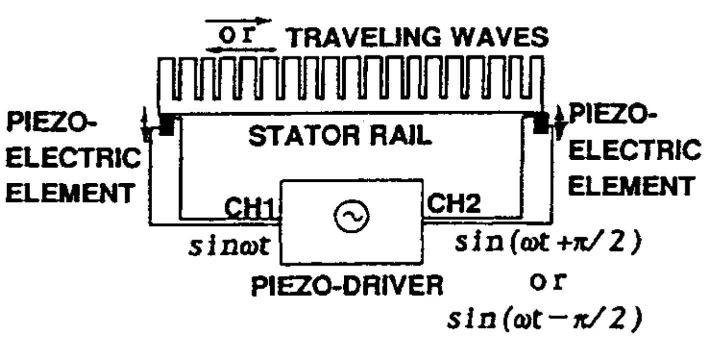

Figure 1.3. The straight finite length rail linear motor (Higuchi, 1995).

The other technique is to use the piezoelectric patches bonded with an elastic medium, producing traveling waves by superposing two standing waves. Figure 1.4 shows a pattern of piezoelectric patches designed so that they can generate two sinusoidal waveforms at different time and location phases (Ueha et al., 1993; Roh et al., 2001). External vibrators are no longer needed in this setup, since the waves are generated by bonded actuator patches. This motor construction is relatively simple and flexible. However, wave reflection at the boundaries is prohibited because this can interfere and distort the pattern of traveling waves. In practice, damping materials are attached to the boundaries to prevent wave reflection. Ultrasonic motors made of a finite length medium (e.g., plates and beams) laminated with piezoelectric actuators have been reported (Tomikawa et al., 1989; Kosawada et al., 1992; Roh et al., 2001), but those are only designed for linear translational motions. Thus, the design of the actuator pattern for the curvilinear arc stator is developed based on those linear translational motors.

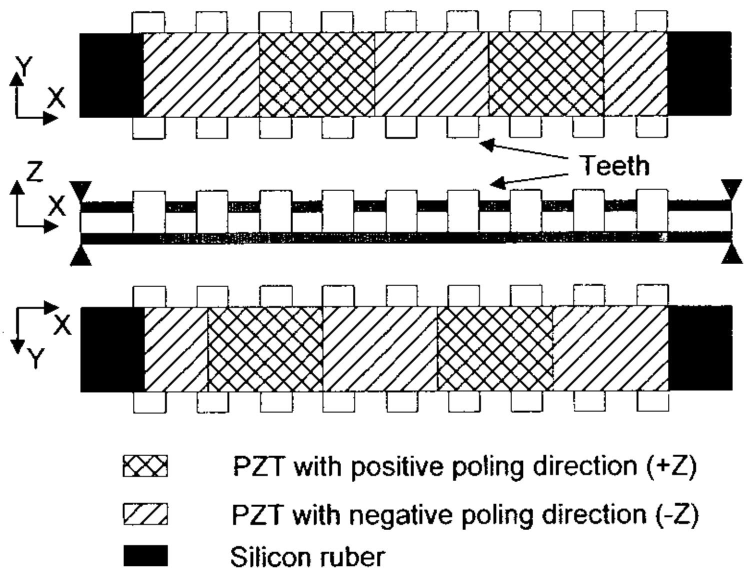

Figure 1.4. Straight finite length beam linear motor (Roh et al., 2001).

Recently, a new design of piezoelectric curvilinear arc motor has been developed as illustrated in Figure 1.5 (Smithmaitrie, 2004). However, there is no analysis of the actuation characteristics in various actuator patterns. Consequently, in this research, the actuation characteristics of the actuator patterns will be study in order to find out the best actuator pattern for generating traveling waves.

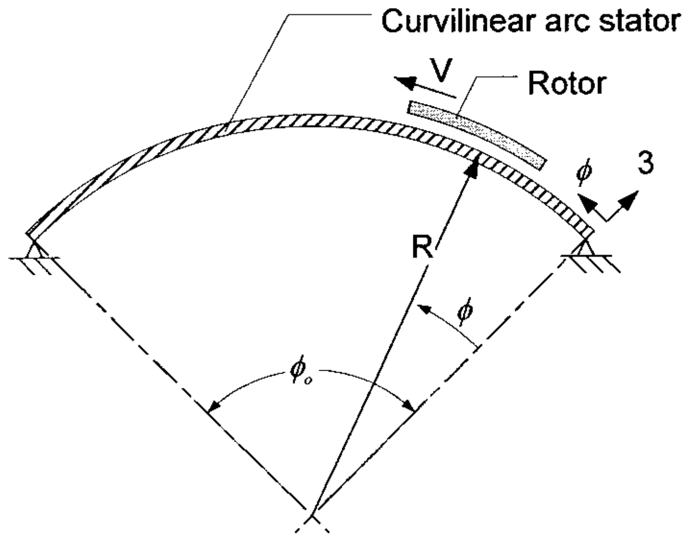

Figure 1.5. Schematic diagram of the curvilinear arc stator/rotor (Smithmaitrie, 2004).

1.6. RESEARCH METHODOLOGY

A methodology will be developed to study the electromechanical characteristics of ultrasonic piezoelectric curvilinear motor. In that methodology, a distributed piezoelectric shell theory will be studied first to develop constitutive equations of the piezoelectric curvilinear motors. Then, fundamental theory of vibration and wave will be applied to develop mathematical models of the systems. The mathematical models will be used to determine the actuator patterns and estimate their operating frequencies that yield stable traveling waves. After that, the designs of actuator patterns will be validated with finite element analysis. Finally, the result will be analyzed and compared to determine the best candidate of actuator pattern.

1.7. SCOPE OF THE RESEARCH

The scope of this project is to study the electromechanical characteristics of piezoelectric actuator patterns of ultrasonic piezoelectric curvilinear motors which can be summarized as follows:

1) Setup the governing equations of the piezoelectric curvilinear motors based on the piezoelectric shell theory.
2) Establish the mathematical models of the piezoelectric curvilinear motors in various designs of actuator patterns and determine operating frequencies.
3) Develop the finite element models of the motors in order to validate the mathematical results.
4) Analyze and design the best design(s) of the actuator pattern to achieve high-performance precision actuation.

1.8. RESEARCH PLAN

Phase	0.5 Year	1 Year	1.5 Year	2 Year
Develop constitutive equations for piezoelectric curvilinear motors				
Determine actuator patterns for generating stable traveling wave on the motors by using numerical simulations				
Develop finite element models of the motors in various actuator patterns.				
Verify the traveling waves and operating frequencies generated by actuator patterns				
Write reports/manuscripts				

1.9. RESEARCH OUTPUT

International Journal:

Smithmaitrie, P., DeHaven, J.G., Higuchi, K. and Tzou, H.S., (2007) "Vibration Response and Harmonic Wave Propagation of Ultrasonic Arc Drivers," *Mechanical Systems and Signal Processing (Journal of)*, Vol. 21(2), pp. 1174-1187. IF 0.826 **(รายละเอียดตามภาคผนวก)**

Presentation:

Smithmaitrie, P., (2006) "Piezoelectric Actuator Patterns and Wave Propagation in Ultrasonic Piezoelectric Curvilinear Motors," The 3^{rd} Meeting of TRF New Researchers Meet Senior Researchers, Oct 12-14, 2006, Cha-am, Petchburi, Thailand, pp. 288. Poster Presentation (P-S3A-12)

Smithmaitrie, P., (2007) "Piezoelectric Actuator Patterns and Wave Propagation in Ultrasonic Piezoelectric Curvilinear Motors," The 4^{th} Meeting of TRF New Researchers Meet Senior Researchers, Oct 11-13, 2007, Cha-am, Petchburi, Thailand, Oral Presentation

Professional Member:

- American Society of Mechanical Engineers (ASME)
- Thai Society of Mechanical Engineers (TSME)

Committee:

- **ASME** Dynamics and Control of Structures and Systems Technical Committee
- Committee of the 19th Conference of Mechanical Engineering Network of Thailand (ME-NETT) (2005), October, 19-21, 2005, Phuket, Thailand.
- Program Chairman of the 2nd Regional Conference on Artificial Life and Robotics 2006, July 14-15, 2006, Songkhla, Thailand.

Reviewer for National Conference:

- The 19th Conference of Mechanical Engineering Network of Thailand (2005)
- The 20th Conference of Mechanical Engineering Network of Thailand (2006)
- The 5th Asian Meeting on Electroceramics (AMEC-5) (2007)

Reviewer for Research Fund:

- Industry/University Cooperative Research Centers in Data Storage Technology and Applications, KMITL

1.10. RESEARCH CONCLUSIONS

This research is to investigate the traveling wave characteristics of a curvilinear motor/stator system when excited with various patterns of piezoelectric actuators and to evaluate the feasibility if this is a viable design option to ultrasonic motors. Operation principle of the curvilinear arc stator was reviewed. Governing equations of the arc stator partially bonded with piezoelectric actuator patches were derived. Dynamic responses of the arc stator system with two configurations (i.e., actuators placed at mid-span or near boundaries - Patterns 1 and 2) were investigated and compared. Both analytical and finite element results demonstrate similar dynamic characteristics of the traveling wave behavior and also effective locations of actuator patches. One of the two case studies suggests that the configuration of partially bonded piezoelectric actuators near the stator supports (i.e., Pattern 2) can generate effective traveling waves. Thus, this configuration is an alternative actuator design to the fully laminated piezoelectric actuators. This study provides important design information of using partially laminated actuators instead of fully laminated piezoelectric actuators on the ultrasonic curvilinear arc motors. The stator/motor system, although with less actuator patches, can still generate effective traveling waves driving the motor. Consequently, the new partially bounded stator/motor system would be lighter and needs less components and less power at reduced cost, easier maintenance and improved reliability.

1.11. LITERATURE REFERENCES

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