

Optimizing Perforated Bellows Formation: Achieving Uniformity and Precision through Proportional Roll Mold Transfer and Length Reduction

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Abstract: This study presents an experimental device designed for single-process formation of perforated bellows through proportional control transfer of the roll mold, ensuring uniformity in thickness and height. A simulation assessed these parameters to establish allowable values, which were validated against experimental data. By implementing a linear acceleration proportional control transfer system for the upper and lower die roll molds, uniform thickness within an error range of 0.02-0.03 mm was achieved. An upper die and lower die roll mold linear acceleration proportional control transfer control system was configured so that ten upper die roll molds and 11 lower die roll molds that form the crests and roots of bellows can be transferred at the same linear acceleration as that of the reduction of the length of the cylinder in the process of manufacturing the crest and root to conduct an experimental study. Experimental findings revealed a minimal thickness error range of 0.02-0.03 mm, demonstrating high uniformity and reliability in the manufactured perforated bellows. Moreover, the study verified the durability and strength of the bellows through thorough assessments of thickness reduction values, which ranged from 0.02 to 0.1 mm. Both experimental and simulated strain rate analyses showed a strong correlation, validating the effectiveness of the proposed manufacturing approach. Therefore, the reliability of the allowable strength and durability of the perforated bellows was secured based on the results of the study on the uniformity of the thickness of the perforated bellows about changes in the thickness of the perforated bellows. Overall, this research establishes a robust methodology for achieving uniformity and reliability in perforated bellows production, offering significant advancements in industrial applications where precise dimensional control and durability are paramount.

Keywords: one-process forming; perforated bellows; proportional control transfer; silencer; uniformity

1 INTRODUCTION

Today, noise is recognized as a significant issue in daily life, and its importance is growing in all industrial fields, particularly in machinery, construction, environment, and electricity [1, 2]. Recently, environmental damage caused by noise has been increasing. As a result, systems are being developed to create a quieter environment by mandating noise-level markings for machinery. Meanwhile, in line with the trend of upgrading machines, not only performance but also additional quality, especially when noises are reduced, greatly affects the competitiveness of machines and is becoming a major criterion for product selection depending on buyers [3]. Thus, noise reduction devices, particularly silencers installed at air intake/exhaust ports close to the user, are urgently needed. Recent advancements in design technology have led to higher output and capacity in fluid machines (e.g., compressors, blowers) and engines. However, this has also resulted in increased noise levels [4, 5]. Consequently, there is a strengthened demand for noise reduction technologies. Research on low-weight, high-performance silencers is urgently needed, but current reports are insufficient [6]. In particular, in the past, manufacturers of finished fluid machinery introduced key technologies for silencer design by paying royalties or making some design changes and then relied on subcontractors for simple manufacturing. However, silencer manufacturers have recently been required to carry out silencer design and evaluation to satisfy necessary performance by themselves. In addition, in the case of high-flow machines, the durability of the silencer must be guaranteed because enormous pressures are generated. Still, since this conflicts with noise reduction performance, appropriate design techniques must be prepared [7, 8]. In particular, in the engine's exhaust system, high-temperature gas of 300 to 400 °C passes

through the pipe at a high speed of 30 to 40 m/s. Noises from the exhaust port can be divided into pulsating noises, which occur when the exhaust valve of a fluid machine opens, and low-pressure outside air is pushed. Flow noises, which occur when the gas flow of the exhaust system is discharged, include a wide range of frequency components ranging from several tens of Hz to several kHz and are discharged with high temperature/high-speed flows so that it is not easy to control exhaust noises [9]. In particular, silencers used for noise reduction must simultaneously satisfy various functions such as minimum back pressure, minimum size and weight, sturdiness and durability, and ease of maintenance, so some studies on systematic silencer design and performance evaluation methods considering temperature, flow rate, etc. have been reported [10]. In particular, recently, as high-output fluid machines are operated in various industrial sites, the development of low-weight/high-performance silencer technology is urgently required [11]. The purpose of a silencer is to attenuate the noises propagated through the interior without interfering with the free flow of the fluid. The current level of silencer technology at home and abroad is largely divided into reactive, absorptive, and reactive-absorptive types according to the operating principles used in research and commercialization [12]. Reactive silencers can generally reduce noise in low and mid-frequency regions, and the impedance mismatch type determines their operating frequency. An absorptive silencer dissipates acoustic energy into heat energy by using a sound-absorbing material on the walls of the flow path [13]. The amount of noise attenuation of this structure is generally proportional to the thickness and length of the sound-absorbing material. It thus is determined by the frequency, the thickness of the sound-absorbing material, and the background material. Due to its operating principle, an effective noise reduction effect can be obtained in the mid-

and high-frequency areas. Reactive-absorptive silencers use the combination of the two types to satisfy the given space and other limiting conditions as much as possible and are the most widely used. In general, in the case of a silencer through which high-speed fluid passes, it is desirable to minimize changes in the flow path and use sound-absorbing materials to reduce noises to minimize back pressure and reduce the occurrence of aerodynamic noises. However, in this case, controlling pulsation noises in the low-frequency region is not easy. Therefore, studies that reflect the optimal area change and acoustic resonator design for reducing low frequencies are required [14]. Therefore, in this study, perforated bellows forming experimental device capable of forming perforated bellows in one process by proportional control transfer of the roll mold according to the length reduction occurring when the crest and root of the bellows are formed was configured. A study on the uniformity and precision of the thickness and height of the perforated bellows was conducted. A transfer control system that proportionally controls the linear acceleration of the upper die and low die roll molds so that the ten upper die roll molds and 11 low die roll molds that form the crests and roots of the bellows with a linear acceleration equal to that of the reduction in the length of the cylinder in the process of manufacturing the crests and roots of perforated bellows was configured to conduct an experimental study. In addition, a silencer that fused perforated bellows technology and micropore stainless chip sound absorber technology was developed to study a silencer with excellent noise attenuation performance even when the fluid pressure is over 30 bar for the first time at home and abroad.

2 EXPERIMENTAL DEVICE AND METHODS

Fig. 1 shows the experimental device capable of forming perforated bellows in one process by proportionally controlled transfer of the roll moulds according to the length reduction occurring when the crests and roots of the perforated bellows occur. As shown in Fig. 1, the perforated bellows forming experimental device was configured as a large experimental device with a length of 3.7 m, a width of 2.5 m, and a height of 4.5 m. The perforated bellows forming experimental device consists of a main body frame, a hydraulic part that generates operating force, a hydraulic cylinder and slide part that controls the ascending and descending of the upper shaft, a hydraulic motor that drives the lower shaft, and an upper and lower molds mounted on the upper and lower shafts, respectively, a servomotor and drive shaft to drive the molds on the upper shaft in a proportional control manner as molding progresses, and a fork that connects the drive shaft and the upper molds. As shown in Fig. 2, in the bellows for mining equipment, a drive motor was installed on the side of the box-shaped frame to rotate the rotating shaft installed in the horizontal direction, and roll molds were constructed so that multiple lower dies and upper dies were installed on the horizontal movement device. The equipment was so built roll molds be produced and installed even if the numbers of crests and roots of the bellows increased or decreased. In addition, the equipment is

designed to facilitate the formation of bellows through a single molding process, where 11 upper die roll molds and 10 lower die roll molds sequentially position themselves at intervals along the idling and rotating shafts, sliding towards the center from both sides to plastically deform the material pipe along its longitudinal direction and match the pitch (the gap between crests) of the bellows being manufactured on the upper and lower sides.



Figure 1 Forming experiment equipment for perforated bellows.

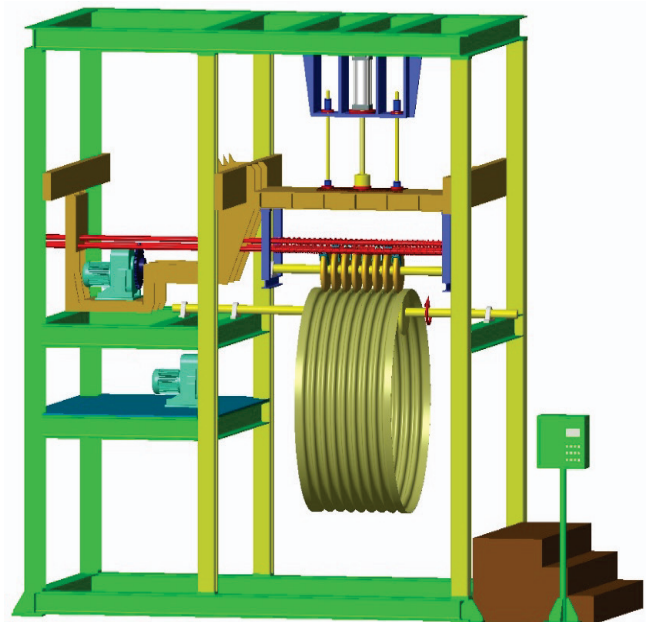


Figure 2 3D schematic diagram of multiple low-die and upper-die roll molds on a rotating shaft

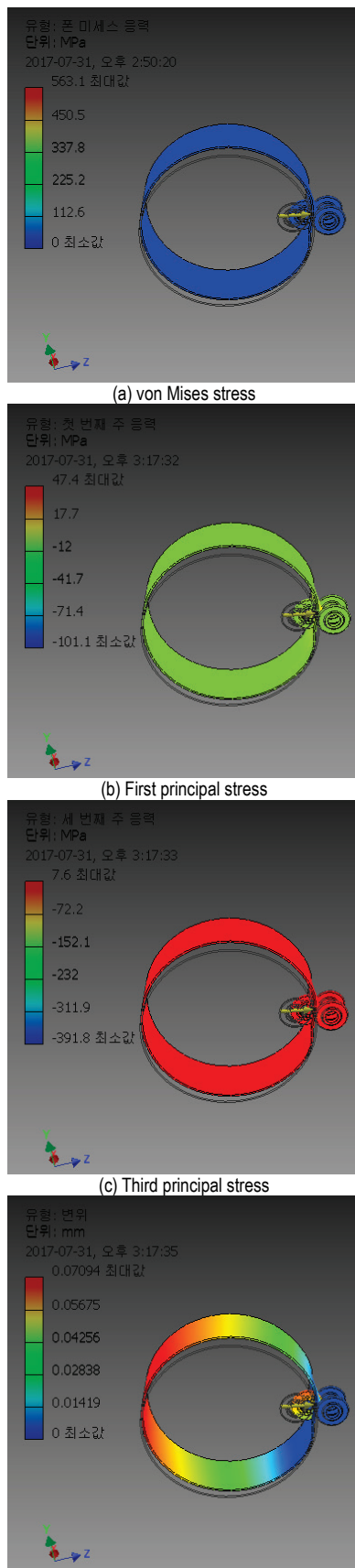


Figure 5 Stress and displacement of one-process formed bellows

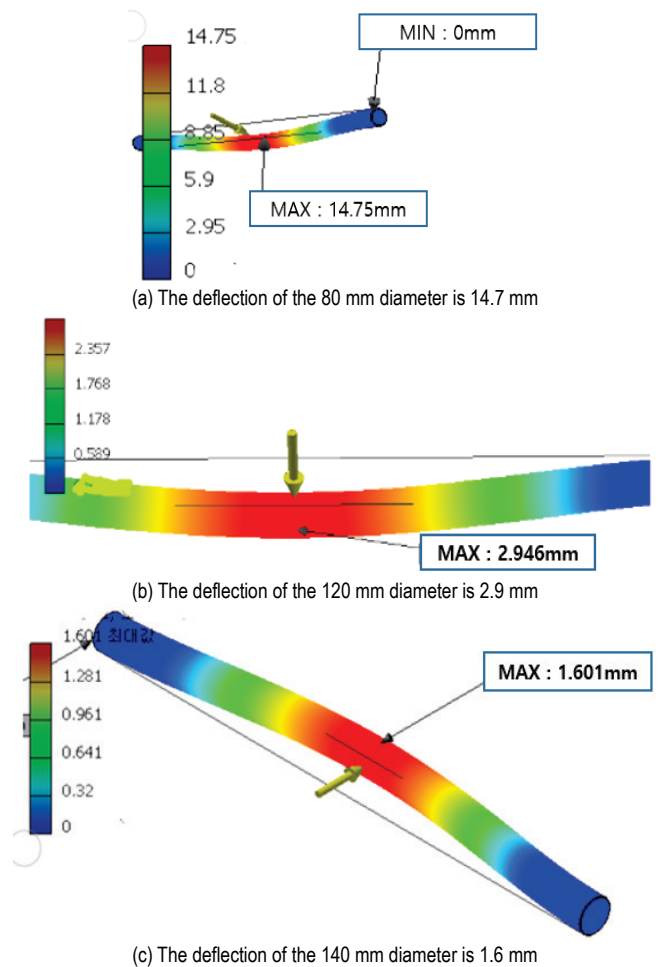


Figure 6 Bending moment simulation for perforated bellows forming experimental device

Fig. 7 shows the shaft diameter calculated from the simulation results for the bending moment of the rotating shaft of the perforated bellows forming the experimental device. As shown in Fig. 7, the shaft deflection was found to be 0.9 mm. Therefore, it is believed that since the resultant deflection value of the shaft is small, the allowable values for the uniformity of the thickness and height of the perforated bellows are secured.

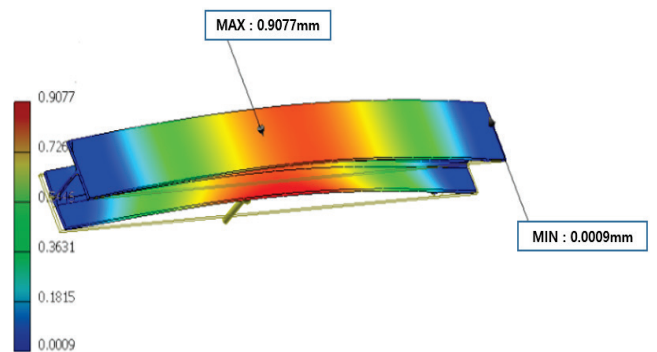


Figure 7 Calculate the allowable diameter of the shaft from simulation results for the bending moment

4 RESULTS AND DISCUSSION

Fig. 8 shows the shape of the perforated bellows. As shown in Fig. 8, the perforated bellows forming experimental device was configured so that ten upper die roll molds and 11 lower die rolls that form the crests and roots of the bellows are transferred at a linear acceleration equal to the linear acceleration of the reduction of the length of the cylinder in the simple process of manufacturing the crests and roots of the simple perforated bellows to implement upper die and lower die roll mold linear acceleration proportional control transfer control system technology thereby forming perforated bellows with one manufacturing process. An experimental study was conducted on the uniformity of the thickness of the perforated bellows by measuring the thickness at five points on the cross-section of the perforated bellows formed as such. In addition, an experimental study was conducted on the height uniformity concerning changes in the pitch of the perforated bellows. Since the thickness and height of the perforated bellows significantly affect their elasticity and durability, the uniformity of the thickness and height of the perforated bellows must be maintained within the allowable values.

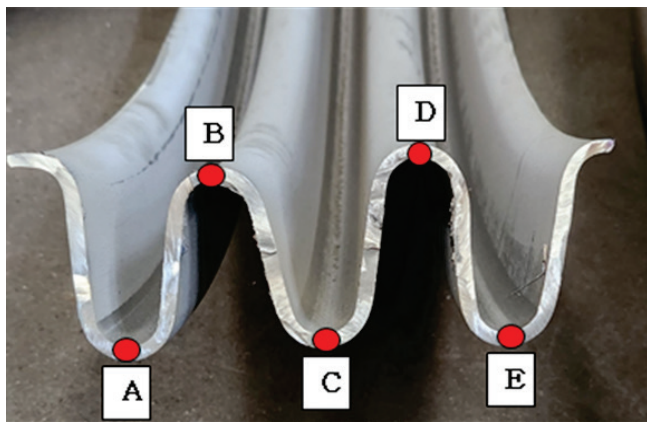


Figure 8 Crest and root of perforated bellows

Fig. 9 shows the uniformity of the thickness of the perforated bellows concerning the changes in the pitch of the perforated bellows. As shown in Fig. 9, an experimental study was conducted under three conditions of the thickness of the perforated bellows: 3 mm, 4 mm, and 5 mm, and as shown in Fig. 9, an experimental study was conducted to verify the uniformity and reliability of the thickness of the perforated bellows by measuring the thickness of the bellows at five cross sections from points A to E. The thickness of the perforated bellows was uniform within an error range of 0.02 to 0.03. Therefore, based on the results of this study, it is believed that the uniformity and reliability of the perforated bellows were secured.

Fig. 10 shows the uniformity of the thickness of the perforated bellows concerning changes in the thickness of the perforated bellows. As shown in Fig. 10, an experimental study was conducted on the uniformity of the thickness of the perforated bellows under five conditions ranging from 1 to 5 mm. The thickness reduction value of the perforated bellows

increased in proportion to changes in the thickness of the perforated bellows. The thickness reduction value of the perforated bellows was in the range of 0.02 to 0.1 mm. Therefore, based on the results of the study on the uniformity of the thickness of the perforated bellows about changes in the thickness of the perforated bellows, the reliability of the allowable strength and durability of the perforated bellows is considered to have been secured. In addition, the uniformity of the thickness of the perforated bellows increased linearly concerning changes in the thickness of the perforated bellows, so the reliability of the experimental results is considered to have been verified.

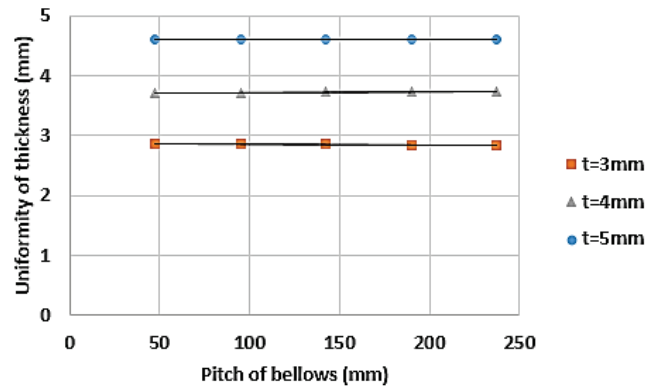


Figure 9 Thickness uniformity for pitch change of perforated bellows

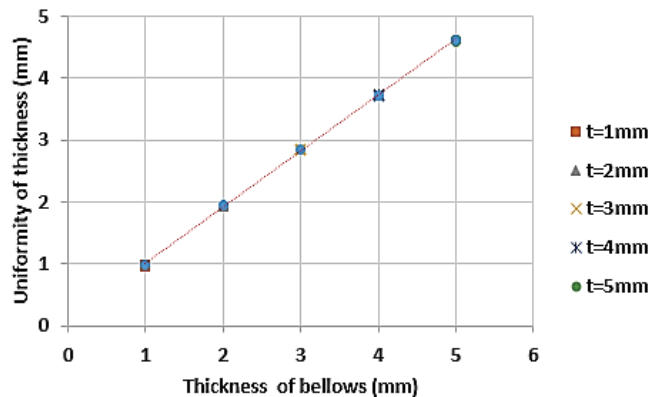


Figure 10 Thickness uniformity for thickness change of perforated bellows

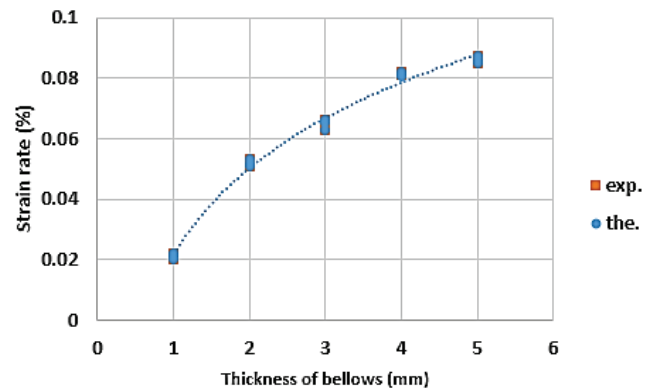


Figure 11 Strain rate for thickness change of perforated bellows

Fig. 11 shows the strain rate of the perforated bellows concerning changes in the thickness of the perforated

bellows. As shown in Fig. 11, a study was conducted to compare experimental values and simulation results for the strain rate of the perforated bellows under five conditions with a thickness of 1 to 5 mm. Based on the results of the study, the experimental and simulation results for the strain rate of the perforated bellows concerning changes in the thickness of the perforated bellows were in relatively good agreement, and the strain rate of the perforated bellows was in the range of 0.021 to 0.086%. The strain rate of the perforated bellows increased in proportion to the thickness of the perforated bellows. Based on the results of the study, the strain rates indicate that the allowable strength and durability of the perforated bellows were secured.

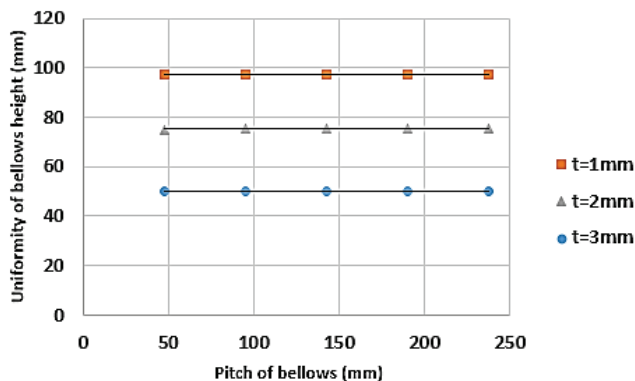


Figure 12 Uniformity of bellows height for the pitch change of perforated bellows

Fig. 12 shows the uniformity of the height of the perforated bellows concerning changes in the pitch of the perforated bellows. As shown in Fig. 12, an experimental study was conducted under three conditions of the thickness of the perforated bellows: 3 mm, 4 mm, and 5 mm. In addition, an experimental study was conducted under three conditions of the height of the perforated bellows: 50.1 mm, 75.2 mm, and 97.2 mm. As shown in Fig. 12, the height of the perforated bellows increased significantly, and the uniformity of the height of the perforated bellows was maintained in the range of 0.1 to 0.3 mm. Therefore, based on the results of the study on the uniformity of the height of the perforated bellows concerning changes in the pitch of the perforated bellows, the uniformity of the height of the perforated bellows was found to be high, so it is believed that the reliability of the experimental results for changes in the height of the perforated bellows was secured.

5 CONCLUSION

In this study, we investigated the feasibility of forming perforated bellows in a single step through proportional control transfer of roll molds, focusing on achieving uniformity and precision in bellows dimensions. Our research successfully implemented a molding technology that achieves this objective, ensuring the thickness of perforated bellows remains consistently uniform within an error margin of 0.02 to 0.03 mm. This uniformity not only enhances the reliability of perforated bellows but also secures their durability and strength under varying conditions.

Furthermore, our experimental and simulation findings concerning the strain rate of perforated bellows align closely with the changes observed in their thickness, ranging from 0.021% to 0.086%. This correlation underscores the effectiveness of our approach in maintaining structural integrity across different thicknesses of perforated bellows. Moreover, as the height of perforated bellows increased, our study revealed a significant enhancement in uniformity, with height deviations consistently maintained within a narrow range of 0.1 to 0.3 mm. This consistency further reinforces the reliability of our manufacturing process in producing perforated bellows with precise dimensional control.

In conclusion, our research demonstrates the successful implementation of a one-process forming technology for perforated bellows, emphasizing uniformity in thickness and height as essential factors contributing to their overall reliability and structural integrity. These findings not only advance current manufacturing capabilities but also pave the way for more efficient and consistent production of perforated bellows in industrial applications.

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