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Development of a Control Method for Speed Pulsation in Escalator's Chain

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INTRODUCTION

Chain drives are used in escalator mechanisms to transfer movement from the motor to the steps and handrails with high-efficiency and synchronization. The chain consists of rollers and links that connect the rollers. The movement of the motor is transferred to the chain by a sprocket that engages the links. However, the rigidity of the links prevent a smooth contact between the chain and sprocket while it is possible with a belt drive. Because of that, the chain winds around the sprocket in a polygonal shape that produces variation in the horizontal speed of the chain even though the sprocket rotates with a steady speed. Such changes in horizontal chain speed are referred to as pulsations. The pulsations are transferred to the steps of the escalator and decrease the comfort of passengers.

The proposed approaches to suppressing pulsation include shaping the chain rail with protrusions or depressions just before the sprocket teeth to vary the horizontal speed of the escalator steps so as to maintain a constant speed within the range where passengers ride [(1)] and to use an inverter to control the motor rotation speed to suppress the pulsation in the horizontal section of the chain.[(2)]

The former approach requires machining the rail into a geometrically-determined irregular shape, and the latter basically requires a means of using the sprocket phase and step speed data as feedback to satisfy the condition of constant drive speed, as well as a control circuit that uses that data to control the motor speed. Both approaches will increase system cost.

This paper proposes a new method to control the pulsation of chain speed keeping the constant rotational speed in the motor. It's a method which makes the roller speed change moving roller track adding a new type of rail next to the sprocket.

CHAIN DRIVING PRINCIPLE

We explain here the operating principle of the chain drive mechanism using the schematic diagram presented in Fig. 1. The chain consists of rollers that are connected at regular intervals by links. The chain winds around a sprocket so that the chain moves when the sprocket turns. The roller speed V_n is expressed by Eq.(1) and Eq.(2).

$$V_n = \frac{\Delta X_n}{\Delta t} = \frac{X_{n-1} - X_n}{\Delta t} \quad (1)$$

$$X_n = \sqrt{P^2 - R^2(1-\cos(n\Delta\theta))^2} - R\sin(n\Delta\theta) \quad (2)$$

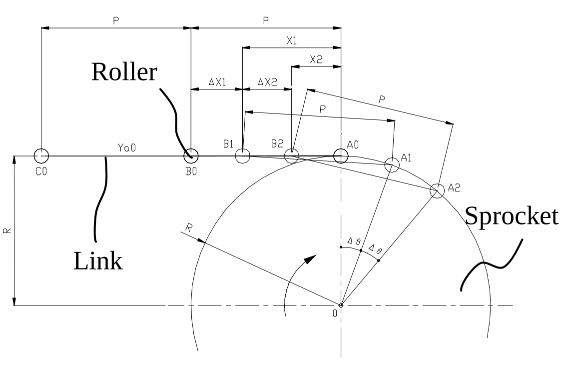


Fig.1 Pattern diagram of an escalator drive part

METHOD OF SUPPRESSING PULSATION

We propose here a mechanical method of suppressing pulsation in which the trajectory of the chain rollers is altered by placing a fixed chain rail that is easily machined and easily installed at the position where the chain turns. The conventional chain mechanism and the proposed mechanism are illustrated schematically in Fig. 2.

In the conventional mechanism, shown in part (a) in Fig. 2, the chain rollers in the rotating part engage the sprocket teeth and move in an arc along the pitch circle and leave the sprocket at the bottom. At that time, because the sprocket moves at a constant speed, the circumferential speed of the rollers is also constant. Nevertheless, a pulsation that corresponds to the length of the chain links occurs in the horizontal sections of the chain.

In the proposed mechanism, on the other hand, the rollers are pulled along by the teeth of the sprocket, but they follow the contour of the fixed rail in the rotating part as shown in Fig. 2 (b). That change in the roller trajectory in the rotating part alters the speed so as to cancel out the pulsation and produce a constant roller speed in the horizontal section of the chain.

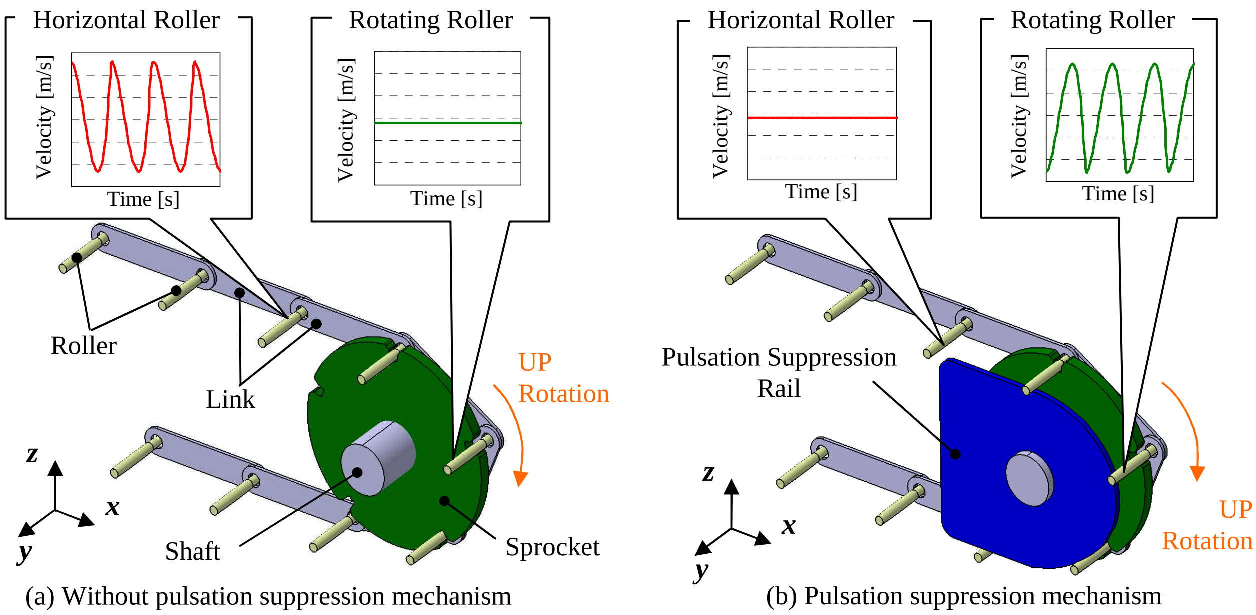


Fig.2 Construction drawing of pulsation suppression mechanism

DESIGN AND ANALYSIS

Pulsation Suppression Method 1. The roller speed in the rotating part is expressed by $V_r = R_r\omega$. In this first design, the radius of the roller from the center of the sprocket in the rotating section, R_r, is reduced to lower the circumferential speed at the position where the horizontal roller speed is higher and R_r is increased to increase the circumferential speed where the horizontal roller speed is lower so as to make the horizontal roller speed constant. (The rotation speed, ω, is constant.)

The path defined by the designed pulsation suppression rail and the roller and sprocket tooth engagement section are illustrated in Fig. 3 (a); the sprocket tooth is illustrated in Fig. 3 (b). We performed kinematics and dynamics analysis simulations in which the sprocket illustrated in Fig. 4 (a) rotated clockwise for upward drive. The waveforms for horizontal chain speed for a movement of one pitch for suppression mechanism 1 and without suppression are presented in Fig. 4 (c) for comparison.

The effect of pulsation suppression mechanism 1 is a reduction of pulse amplitude by 18% for upward drive relative to the case without suppression. However, some change in speed occurs, and we understand from the analysis results that the design of path before and after roller and sprocket engagement is important.

Pulsation Suppression Method 2. Based on the results obtained with proposed method 1, we designed a new chain rail and tooth shape that takes into account point; it is to make the path just before and after the onset of roller and sprocket tooth engagement as smooth as possible. An additional constraint on the second design is that there be no change in height so that existing escalator components can be used without modification.

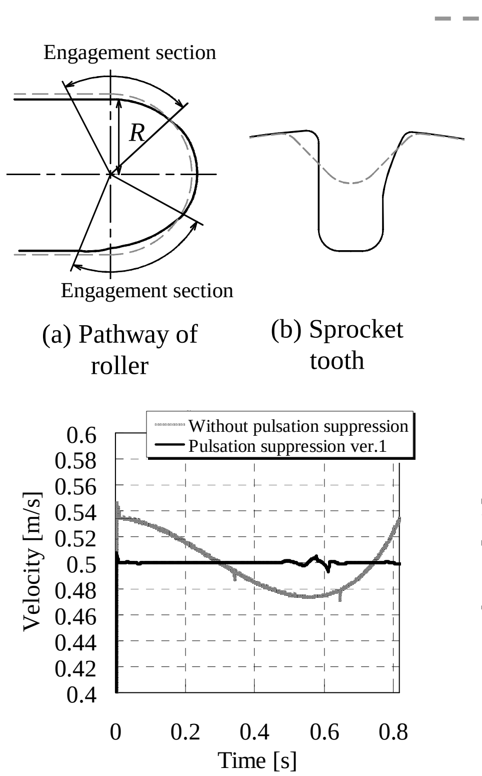
The rail shape (path) and the roller engagement section designed for method 2 are illustrated in Fig. 4 (a) and Fig. 4 (b) show the sprocket tooth shape. Fig. 4 (c) respectively presents the simulation results for the speed of horizontal roller movement of one pitch length under suppression method 2 and without suppression.

We see from Fig. 4 (c) that the speed pulsation is controlled to produce a constant horizontal speed. These results confirm that suppression method 2 can reduce the pulsation amplitude by 2% for upward driving relative to the case without suppression.

After the simulation confirmed the speed pulsation suppression effect of the proposed method, we next fabricated a prototype pulsation suppression rail and sprocket, and installed them on an actual escalator to test the suppression effect.

The results of the prototype testing revealed almost no difference in the comparison of waveforms with current escalators, but they did confirm, in part, changes in speed that were not observed in the simulations.

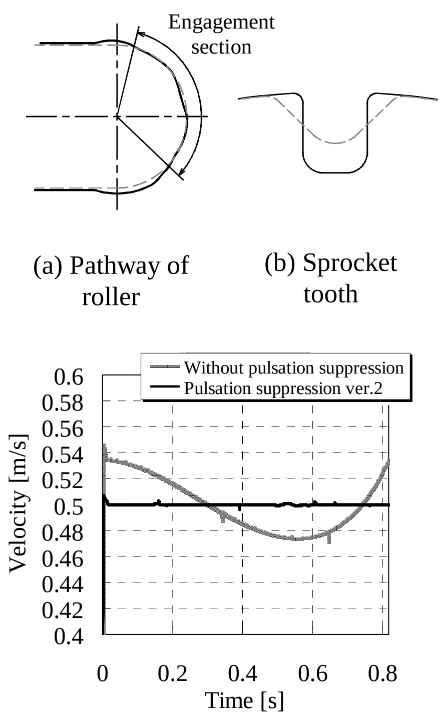
We discuss those speed variations with reference to Fig. 6. In current chain mechanisms, the roller engages with teeth that have a circular bottom as we see in Fig. 6 (a), so the roller position is uniquely determined by the sprocket and does not move within the tooth shape regardless of the tension on the links to the left or right.



(a) Pathway of roller (b) Sprocket tooth

(c)Simulation results of roller speed

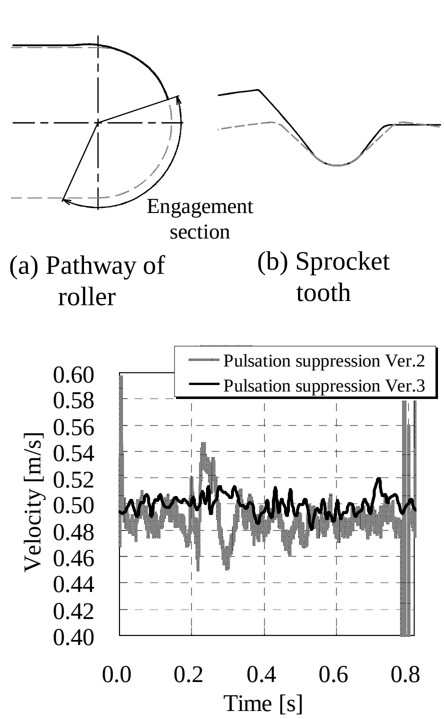
Fig.3 Pulsation suppression mechanism ver.1



(a) Pathway of roller (b) Sprocket tooth

(c)Simulation results of roller speed

Fig.4 Pulsation suppression mechanism ver.2

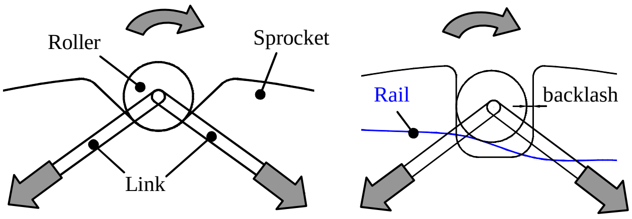


(a) Pathway of roller (b) Sprocket tooth

(c)Experimental results of roller speed

Fig.5 Pulsation suppression mechanism ver.3

In method 2, on the other hand, as shown in Fig. 6 (b), the roller position is determined by both the sprocket and the pulsation suppression rail. As a result, the roller can move by the amount of backlash allowed by the sprocket tooth shape, and moves within the tooth shape due to the tension of the links. Experiments have shown that such movement results in variation in chain speed.



(a) Without pulsation suppression (b) Pulsation suppression mechanism Ver.2

Fig.6 The cause of generating of speed pulsation

Pulsation Suppression Method 3. Building on the results obtained for method 2, we proposed pulsation suppression method 3 to solve the problem of the movement of the roller within the tooth shape.

Method 3 has two features; one is pulsation suppression rail that is placed only in the section of the rotating part defined by the angle through which a single roller, and the other is round-bottomed sprocket tooth. Because the only thing that affects the horizontal speed of a roller is the roller that is in front of it and is in the rotating section, the pulsation suppression chain rail is placed only in the section defined by the angle through which one tooth of the sprocket advances. In the section where there is no chain rail, the roller engages the sprocket firmly at the bottom of the tooth and does not move within the tooth.

The roller path of the pulsation suppression chain rail designed for method 3 and the section in which the roller and sprocket engage are illustrated in Fig. 5 (a); the sprocket tooth shape is illustrated in Fig. 5 (b).

We fabricated a prototype chain rail and sprocket that implement method three, installed them in an actual escalator, and measured the roller speed in the horizontal section of chain. The results for a movement distance of one pitch for method 2 and method 3 are presented in Fig. 5 (c). In proposed method 3, there is no movement of the roller within the sprocket tooth, and the variation in chain speed is greatly suppressed.

CONCLUSION

We have proposed here a mechanism for producing a constant horizontal chain speed to suppress the phenomenon of speed pulsation that is caused by polygonal motion in a chain drive. The proposed method places a fixed chain rail at the drive sprocket to alter the trajectory of the chain rollers so as to geometrically achieve constant horizontal chain speed. The shapes of the fixed chain rail and sprocket teeth were designed with progressive improvement by performing analysis with a computer-aided kinematics and dynamics tool and testing the result in an actual machine to produce three methods successively.The final result is confirmation of the pulsation suppression effect by installation of a prototype in an actual escalator.

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