SEAT SUSPENSION SYSTEM FOR IMPROVING RIDE COMFORT

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Introduction

Farm mechanization developed over the past 20 years. Number of tractors exceeds 1,5000,000 and tractors are recognized as one of the most important machines to develop the farm mechanization. The tractors are operated on rough terrain such as farm fields, meadows and unpaved roads, but most of the tractors are not equipped with a suspension system. Therefore, tractor operators suffer from the severe vibration of the tractor which may even damage the farmer's health[15]. Many investigators have tried to improve the ride comfort[4,7,8,9,10,13,14,16,17] and P. W. CLAAR II reviewed many investigations[2].

There are some successfully modified tractors with a front and rear axle suspension system, for example TRANTER developed by NIAE (National Institute of Agricultural Engineering, U. K.). But the axle suspension system is very complicated, so most investigators have tried to improve the ride comfort of tractor operator by adopting seat suspension systems. Seat suspension systems are classified into two systems; one is a passive suspension system and the other is an active suspension system. The passive suspension system decreases vibration acceleration by spring and damper. The active suspension system decreases vibration acceleration by maintaining an instantenious dynamic equilibrium for the operator and this system consists of a vibration sensor, an electrical circuit and some hydraulic components, thus the active suspension system is complicated and very expensive. Therefore most of seat suspension systems are passive suspension systems.

Most of the imported tractors and some Japanese larger tractors are equipped with passive suspension systems, and they are refered to as "suspension seat". It seems that the number of tractor equipped with suspension seat will increase in the near future. Thus it is necessary to evaluate the improvement of the ride comfort of tractor operators by adopting a suspension seat.

The purposes of this work are (1) to investigate the improvement of the ride comfort for tractor operator by changing from the conventional hard pan seat to a suspension seat, (2) to point out the advantages of the suspension seat and adopt the same, (3) to consider the possibility of further improvement of commercial suspension seats.

Equipment and procedure

Seats and tractor

In order to investigate the improvement of the ride comfort for tractor operators, a conventional hard pan seat (seat A) with a cushion and a commercial suspension seat (seat B) with coil springs and a damper were used (Fig. 1, 2). Seat A was an original seat of a test tractor and seat B was designed by a foreign manufacturer and made by a Japanese manufacturer. A 29 kW (39 PS), pneumatic tired tractor was used as the test vehicle. The

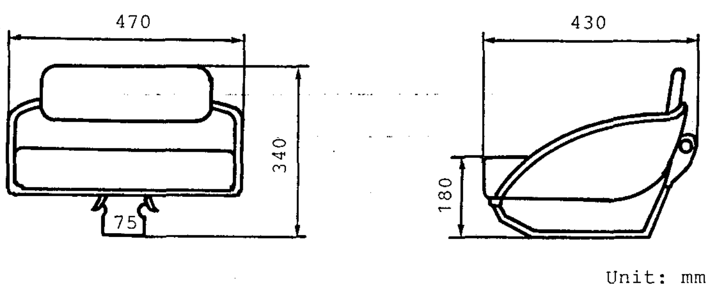

Fig. 1. A hard pan seat.

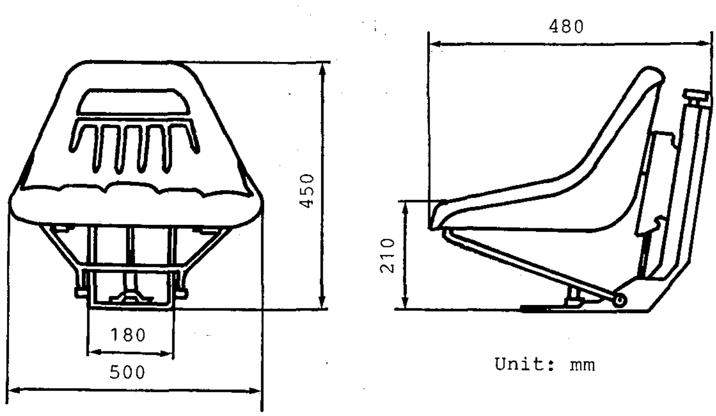

Fig. 2. A suspension seat.

total mass was 1550 kg and the mass of a test operator was 75 kg.

Accelerometer

Acceleration of the tractor body and the seat were measured on the vertical axis using two strain gauge linear accelerometers. One accelerometer was fixed to a plate and covered with silicon rubber to measure the acceleration of the seat and the operator sitting on this equipment. This equipment was made according to ISO 5008[6]. Another accelerometer was fixed to the tractor body under the seat to measure the acceleration of the tractor.

Procedure

The stiffness and the damping ratio of the seat were the main parameters to evaluate the characteristics of the suspension seat, thus the load-deflection curve and free vibration behaviour of seats were measured. A firm dry grassland was selected to measure accelerations of the seat and the tractor body. The roughness of the test track was somewhat smoother than the standard test track of ISO 5008 (rougher)[6] (Fig. 3).

The frequency range covered was 0–20 Hz, because the principal body

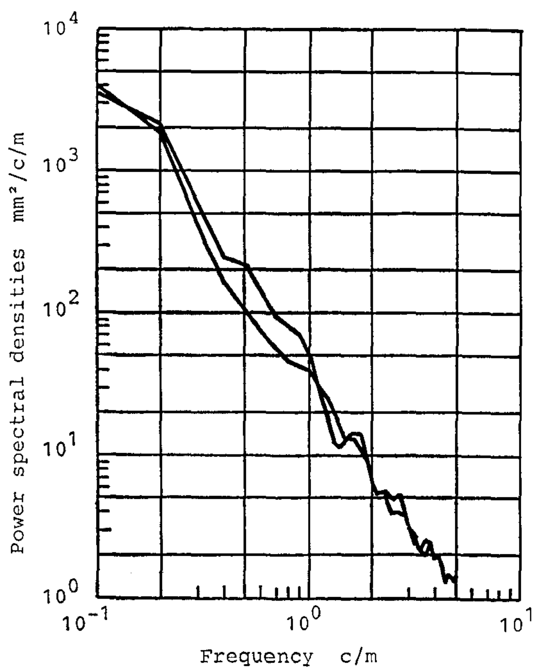

Fig. 3. Roughness of test tracks

resonance made may have occurred in the range of 4–8 Hz[4] and the vibration caused by the irregularities of terrain may have occurred below 10 Hz.

Results and Discussion

Characteristics of seats

Fig. 4 shows a load-deflection curve of seat A and Fig. 5 shows a load-deflection curve of seat B. The load-deflection curve was determined by a complete cycle from zero to maximum load, again returning to zero load.

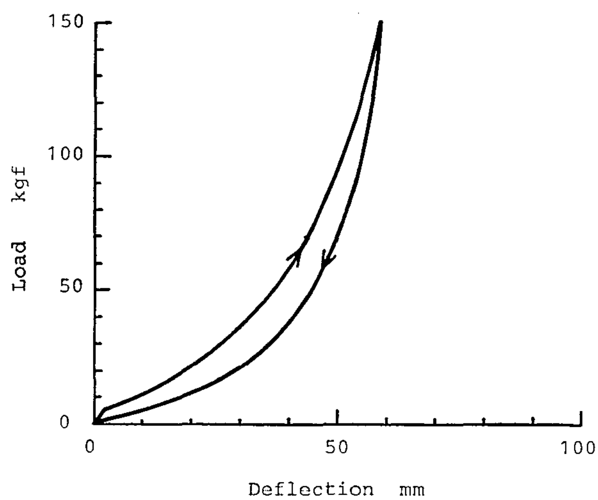

Fig. 4. Load-deflection curve of seat A.

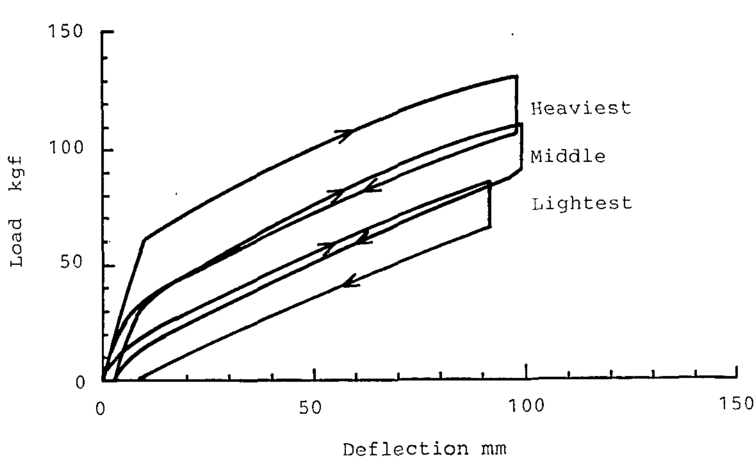

Fig. 5. Load-deflection curves of seat B.

TABLE 1. Characteristics of seats

Seat	Weight adjustment	Static stiffness (kN/m)	Damping factor
A	—	40.5	0.25
B	Lightest	7.1	0.20
	Middle	9.1	0.17
	Heaviest	10.1	0.13

Fig. 4 and 5 show the load-deflection curves from a closed loop, and the closed loop means that the system has hysterisis characteristics. Seat B was equipped with a weight adjustment and Fig. 5 shows the load-deflection curves of seat B adjusted at the lightest, the middle and the heaviest position. The maximum deflection for seat A was half of the deflection for seat B. Tab. 1 shows the static stiffness and the damping factor of the tested seats. The static stiffness at the operator's weight was calculated and the damping factor was a ratio of the damping coefficient to the critical damping coefficient.

Improvement of ride comfort

Fig. 6 shows the acceleration ratios. Acceleration ratio was the ratio of the acceleration of seat to the acceleration of tractor body. The value of the acceleration ratio smaller than 1.0 means that the acceleration of seat is smaller than that of the tractor body, namely, and the ride comfort is improved. The acceleration ratio of seat B was smaller than that of the

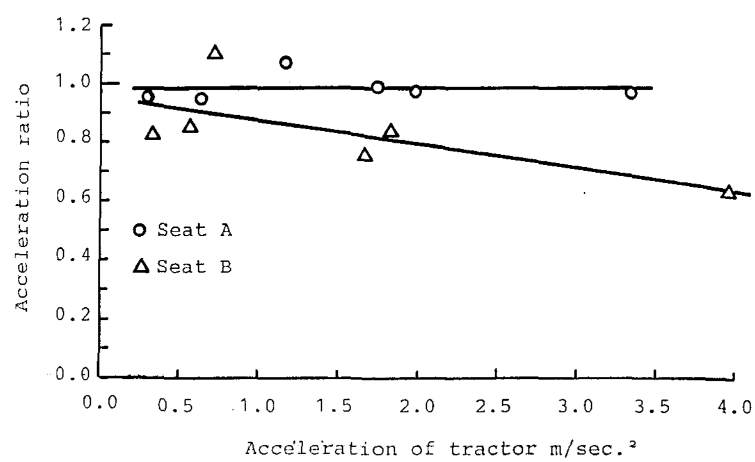

Fig. 6. Acceleration ratio of seat A and B.

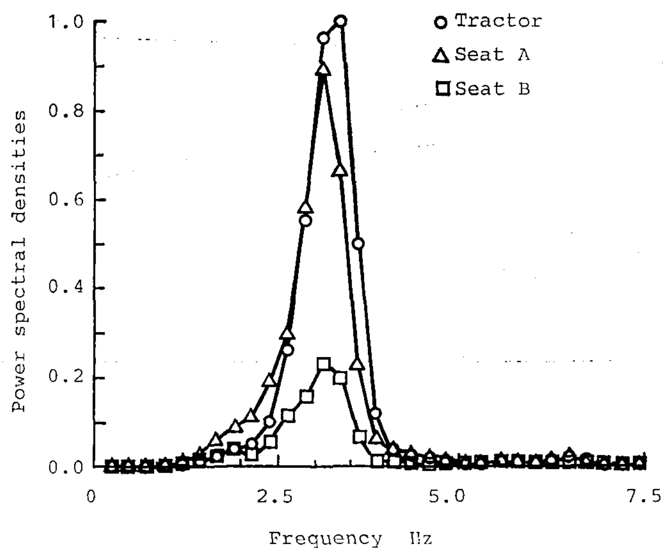

Fig. 7. Power spectral densities of accelerations.

seat A, and the acceleration ratio of seat A was larger than 1.0. Therefore it appears to be effective for the improvement of ride comfort to adopt a suspension seat instead of a conventional hard pan seat.

Fig. 7 shows the power spectral densities (PSD) of accelerations of the tractor body, seat A and seat B at the tractor speed of 3.0 m/sec.. A random vibration can considered to be the sum of a large number of harmonic vibtrations of appropriate amplitudes and phase. The total power is again the sum of the power of the component harmonic vibrations, and it is of interest to know what manner this power is distributed as a function of frequency. Therefore the power spectral density is defined as the power per unit frequency interval. A plot of this quantity indicates the frequency distribution of power[3].

The peak frequency of PSD of the tractor body vibration was about 3.5 Hz. The peak value of PSD of seat B was one fourth of the tractor body, but the peak value of PSD of seat A was the same as the tractor body. This showed that the acceleration of seat B was smaller than that of seat A. The natural frequency of seat A was 3.8 Hz and that of seat B was 1.8 Hz. The natural frequency of seat A was equal to that of the tractor body, then resonance vibration occurred and the peak value of PSD of the seat was larger than that of the tractor body. Therefore it is suggested that the lower natural frequency of seat improves the ride comfort.

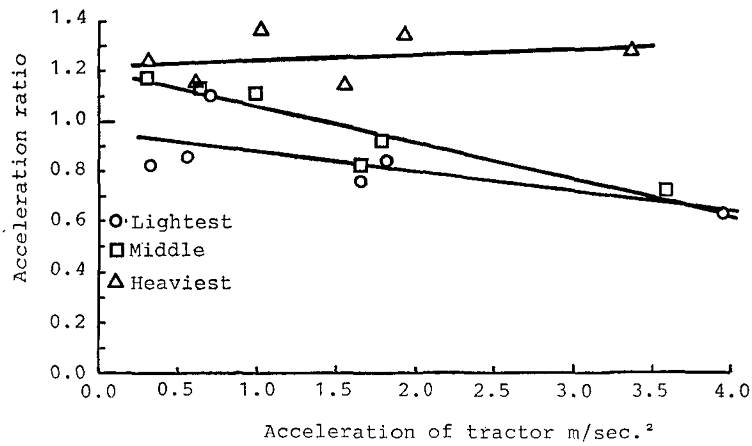

Fig. 8. Effect of the weight adjustment.

Fig. 8 shows the effect of the weight adjustment of the suspension seat on the improvement of ride comfort. The load-deflection curve of seat B (Fig. 5) shows that the optimum adjustment to the test operator will obtained at "the middle". When the weight adjustment was the lightest position, the seat extended to the bottom. And when the weight adjustment was at the heaviest position, the seat was not deflected and the static stiffness was large. Then, if the weight adjustment dit not fit the operator, the suspension seat would not be effective. And ride comfort would not be improved.

Fig. 5 shows that the weight of operator is in the range of 50–115 kg for seat B. It seems that the range of the weight adjustment is slightly heavier for Japanese.

The influence of static stiffness of a seat

Fig. 9 shows the load-deflection curves of a seat to which were attached four kinds of coil springs. Weight adjustment in each case was adjusted to the test operator's weight position. K 3 was the original spring. The static stiffness of K 1 was almost half of K 3. K 2 was almost three quarters of K 3 and K 4 was nearly twice of K 3. The smaller the static stiffness of the seat the better the ride comfort, because the natural frequency of the seat decreases. However, if the static stiffness of seat is not large enough for the operator's weight, the seat may sink to the bottom and the ride comfort would not be sufficiently improved. Fig. 9 shows the static stiffness of K 1 was not large enough for the operator, but the stiffness of K 1 may be suitable for the operator who has a mass of 40 or 50 kg.

Fig. 10 shows the influence of static stiffness of the suspension seat on

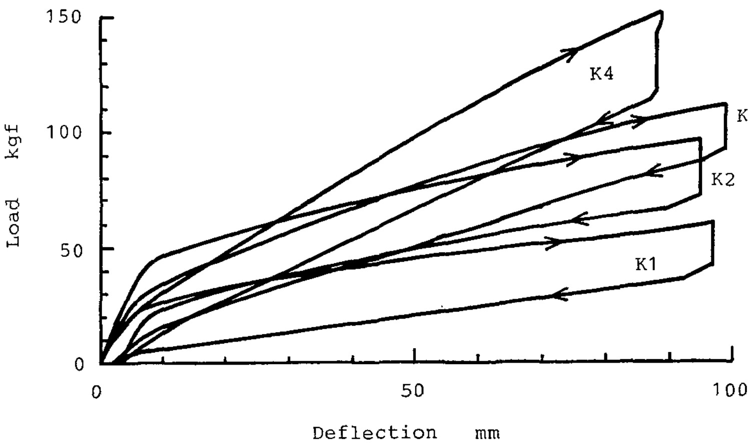

Fig. 9. Load-deflection curves (K1, K2, K3, K4).

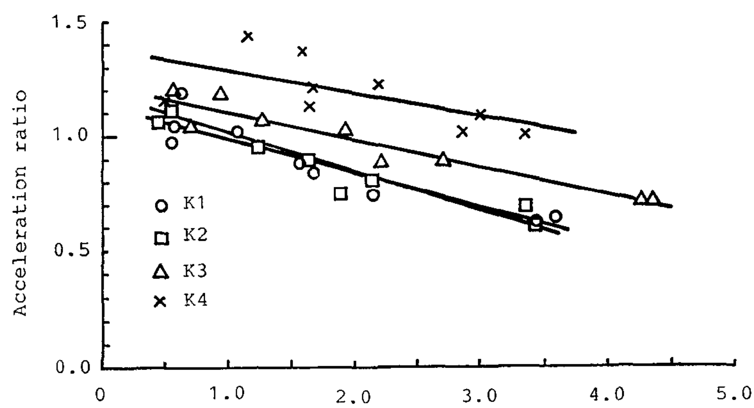

Fig. 10. Influence of static stiffness.

the improvement of the ride comfort. The ride comfort was improved by adopting the seat which was equipped with a coil spring of smaller static stiffness. The natural frequency was 1.1 Hz (K 1), 1.5 Hz (K 2), 1.8 Hz (K 3) and 2.4 Hz (K 4) for the test operator (75 kg). When the mass of operator is 50 kg and the coil spring of the seat is K 1, the natural frequency may be 1.3 Hz. When the mass of the operator is 90 kg and the coil spring of the seat is K 3, the natural frequency may be 1.6 Hz.

It is recommended that the ride comfort for tractor operator may be improved by adopting the proper static stiffness of seat for the operator's weight.

Summary

To investigate the improvement of ride comfort for tractor operators by adopting a suspension seat, the vertical accelerations of a hard-pan seat and a suspension seat were measured and analyzed. And also to investigate the influence of the static stiffness of the suspension seat on the improvement of ride comfort, the suspension seat was equipped with four kinds of coil springs and the vertical accelerations were measured and analyzed.

Certain conclusions were led forth and described as follows.

1) It is recommended that the ride comfort for tractor operator will be improved by adopting a suspension seat instead of a conventional hard pan seat and there seems about 40 percent decreases in the vertical acceleration by adopting a suspension seat.

2) The weight adjustment of the suspension seat strongly influenced the ride comfort. When the weight adjustment fit the operator's weight, the ride comfort was considerably improved. But when the weight adjustment did not fit the operator's weight, the ride comfort was not improved and the acceleration of the seat was larger than that of the tractor body.

3) Since the smaller the static stiffness of the suspension seat became lower the natural frequency was and the smaller the static stiffness of the seat was the better the ride comfort became. However, when the static stiffness of the seat was too small for the operator, the seat was greatly deflected and reached the bottom when the operator sat on it. And when the static stiffness was too large for the operator, the seat was not deflected and the ride comfort was not improved. Thus it is suggested that the static stiffness should fit the operator's weight and the natural frequency of the seat should be smaller than or equal to 1.5 Hz.

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