

DESIGN AND EXPERIMENTAL ANALYSIS OF THE SENSOR FOR MEASURING THE LATERAL FORCE OF LIQUID MEDICINE SLOSHING IN THE SPRAY BAR SPRAY

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To investigate the transverse force of liquid shaking in the medicine cabinet, a lateral transverse force measurement sensor was designed. Experiments were conducted to measure the lateral force of the 3WPJ-500D sprayer at 3 driving speeds and 6 liquid adding volumes. The results showed that the shaking lateral force of the medicine cabinet was an alternating load, and the maximum amplitude can reach 1540N, which is equivalent to 19.25% of the full load weight of the sprayer. Calculating the root square value of the lateral force of liquid shaking, it is known that the increase of volume and driving speed will affect the lateral force of liquid shaking of the spray machine medicine. However, if the speed was constant, the volume of liquid medicine will exceed 80% of the cabinet capacity. Due to the constant vibrating liquid, an increase in lateral force of fluid vibration will be no longer significant.

Keywords: boom sprayers; liquid shaking transverse force; transverse force measurement

1. Introduction

Speelman first pointed out that liquid volume would affect the end movement of the spray rod [1]. Joen measured the three-way acceleration of the rear axle center, spray rod center and spray rod end under actual road excitation [2]. Jen et al. believed that the increase of the cabinet would lead to an increase in the amplitude of the center of the spray cabinet and the center of the spray. A platform with a large volume liquid tank will be stimulated by the road surface, and the shaking liquid will generate additional force [3-4]. Therefore, the shaking liquid is also a factor that affects the movement of the sprayer. Speelman and Joen et al. [1-2] focused on the effect of the dosage on the uniformity of the spray deposition. They did not explain the effect of the dosage on the movement of the sprayer from the mechanical behavior of liquid shaking.

The problem of liquid shaking in the tank has been widely studied in the fields such as liquid tank truck [5-11]. The basic consensus is that liquid shaking will generate additional force, affecting the overall movement of the machine. Hu

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Xiaoming analyzed the influence of driving speed and adding volume on the stability of the liquid tank car under different driving conditions. It indicated that the lateral force of liquid shaking would reduce the rollover stability of the liquid tank car, and the transverse force will make the "swing" of the liquid tank car unstable. The road conditions of the sprayer were more complex and harsher than those of liquid tank truck [12-14]. It is easier to stimulate liquid shaking in the tank to generate additional force. Due to the high ground clearance of the sprayer, the lateral force generated by the shaking of the large capacity medicine box on the sprayer will increase the danger of rollover and reduce the driving stability of the sprayer. In addition, the lateral force of liquid shaking in the medicine cabinet will affect the movement of the spray rod. The movement of spray rod is closely related to the uniformity of spray deposition [15]. Therefore, it is of great practical significance to study the additional lateral force generated by the liquid shaking in the medicine box of the sprayer rod.

We designed a lateral force measurement sensor to measure the lateral force of liquid shaking and measure the lateral additional force caused by the shaking.

2. Materials and Methods

2.1 Mechanical analysis of liquid shaking in the sprayer medicine cabinet

Due to the excitation of field road surface, the sprayer rod will drive the liquid shaking of the medicine cabinet to generate additional force. The mechanical analysis of liquid shaking in the medicine cabinet is shown in Fig.1. The lateral (y direction) translation and rolling movement (around x rotation) will cause dynamic pressure on the liquid along the y direction, resulting in additional lateral force F_y . Similarly, the longitudinal (x direction) translation and pitch motion (around y rotation) of the medicine cabinet will generate a dynamic pressure along the x direction of the liquid, resulting in additional longitudinal force F_x . An additional torque M_x is generated by shifting the center of mass in the transverse (y direction), and an additional torque M_y is generated in the longitudinal (x direction). The z - axis is subjected by the gravity (mg) of the liquid.

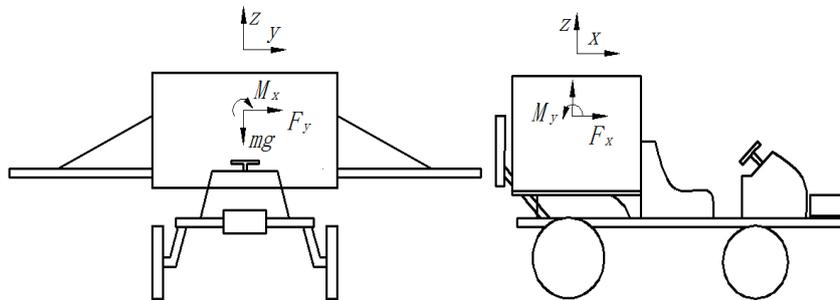


Fig. 1 Mechanical model of sprayer reservoir shaking

2.2 Measurement system for the lateral force of liquid shaking in medicine cabinet

The measuring system consists of a DC power supply, a transverse force measurement, a lateral force measurement sensor, a dynamic strain meter (BZ2004), a data acquisition instrument (BZ7120-USB), and a computer and signal analysis software. The transverse force measurement force-sensitive element uses the change of strain under the transverse force F_y to generate the voltage signal by measuring the strain changes, where the corresponding transverse force is measured by measuring the voltage signal F_y [16-17].

The strain gauge of the transverse force measures the lateral force measurement sensor and the bridge box of the dynamic strain gauge, which transforms the strain generated by the lateral force of the medicine cabinet into the voltage signal to the dynamic strain gauge. The dynamic strain gauge is connected to the input channel of the data collector through a BNC data line, and the output voltage in the strain gauge measurement circuit is amplified and filtered to the data collector. The data collector is connected to the computer through the USB interface, and the sampling frequency, storage path and other functions of the data collector are set by the signal analysis software. The DC power supply supplies the dynamic strain gauge. The data collector sample frequency is 100Hz; the magnification of the dynamic strain gauge sensitivity is 10, and the calibration value is $900 \mu\epsilon$.

2.2.1 Design of the lateral force measurement sensor for measuring the lateral force of liquid shaking in the medicine cabinet

According to the analysis of the kinetic model of the medicine cabinet, the sprayer is affected not only by the lateral force of liquid shaking, but also other directions. To ensure the force sensitivity in the main measurement direction, the interference of the output signal of the strain element in other directions should be minimized. Therefore, a reasonable structural design and layout method for the force sensitive component was carried out, as shown in Fig. 2.

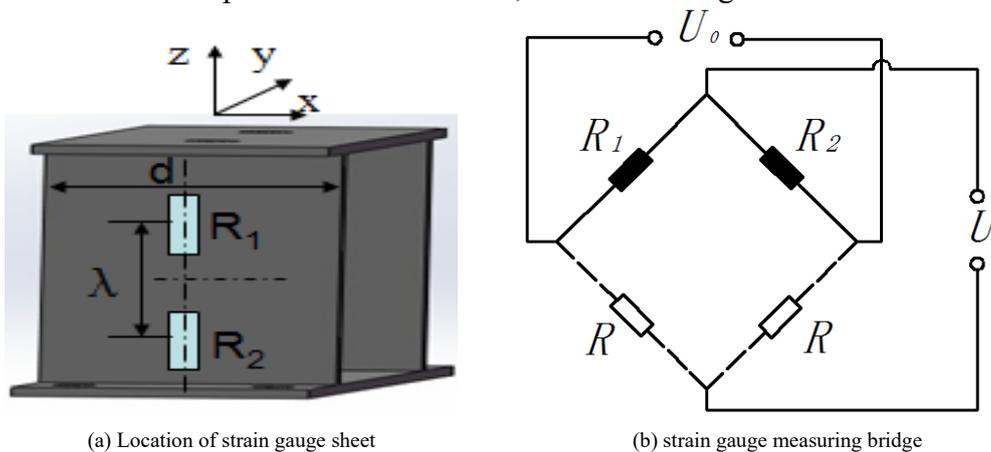


Fig. 2 Schematic diagram of strain sheet arrangement mode

To make the sensitivity of the lateral force measurement sensor to the transverse force F_y response greater than that to the longitudinal force F_x . The lateral force measurement sensor was designed as $d=11\delta$. The strain gauge R_1 and R_2 were arranged on the vertical symmetry line of the main deformation body, and the two strain gauges were symmetrical vertically with a distance λ of 100mm. The strain gauge R_1 and R_2 with a standard resistance R of 120Ω was inserted into a strain gauge measuring bridge. When $R_1=R_2=R$, the strain gauge measured the circuit output voltage a [18-19]:

$$U = \frac{R(\Delta R_1 - \Delta R_2)}{2R(2R + \Delta R_1 + \Delta R_2)} U_0 \quad (1)$$

When $\Delta R_i \leq R$

$$U = \frac{\Delta R_1 - \Delta R_2}{4R} U_0 = k_i \varepsilon_i U_0 \quad (2)$$

where U_0 - the power supply voltage;

ΔR_i - Change value of each resistance, $i=1,2$;

k_i - Sensitive coefficient of resistance strain gauge, $i=1,2$;

ε_i - Strain of the strain gauge, $i=1,2$.

When the lateral force measurement sensor is subjected to the lateral force F_y , different force arms of the lateral force F_y at R_1 and R_2 will cause different sizes of strain in R_1 and R_2 , thereby causing the strain gauge to measure the corresponding voltage output of the bridge circuit. When the lateral force measurement sensor is subjected to the torque M_x , the torque causes R_1 and R_2 generate the same strain due to the transfer characteristics of the torque M_x . According to formula 2, the bridge output of the strain gauge is 0. Similarly, when the force-sensitive element is subjected to the torque M_y , the strain gauge measurement bridge output voltage is also 0. When the lateral force measurement sensor is subjected to the vertical direction gravity (mg), the strain gauge on the bridge road is compressed at the same time. The resistance change of each strain gauge is the same, and then the output voltage of the bridge road is still 0.

The main technical parameters of BX 120-3AA foil strain sheet are shown in Table 1.

Table 1

Main technical parameters of strain			
Parameters	Numeric values	Parameters	Numeric values
Resistance value / Ω	119.9±0.1	Sensitivity	2.08±1%
Transverse sensitivity ratio	5% At room temperature	Size (Gate length and gate width)	3×3mm

2.2.2 Test calibration of the lateral force measurement sensor

To obtain the relationship between the output voltage of the designed lateral force measurement sensor and the transverse force of liquid, the force element was installed in a special calibration frame, and the length of the calibration force arm

is 0.2m. Calibration was performed by loading and unloading weights along the lateral force measurement sensor $\pm y$ [19]. The calibration test was repeated three times, and the calibration data are shown in Table 2.

Table 2

Calibration weight mass / kg		Calibration data / mv					
		The first cycle		The second cycle		The third cycle	
		loading	unload	loading	unload	loading	unload
y direction	0	0	4	0	2	0	3
	30	228	227	231	227	228	228
	60	433	437	436	436	436	436
	90	665	660	666	665	661	664
	100	876	880	878	883	880	883
	150	1118	1118	1120	1120	1115	1115
-y direction	0	0	-9	0	-6	0	-4
	30	-225	-224	-224	-250	-228	-232
	60	-432	-437	-436	-439	-437	-436
	90	-675	-672	-670	-677	-674	-674
	100	-889	-884	-895	-884	-888	-887
	150	-1117	-1117	-1121	-1121	-1126	-1126

If the y direction is positive, 1kg weight is equivalent to loading a lateral force of 10N, and the calibration data of the force-sensitive element is fitted using the least squares method. The linear relationship between the resulting output voltage value U (mv) and the transverse force F_y (N) is calculated as follows:

$$U = 0.742F_y - 2.319 \quad (3)$$

Based on the calibration data and the fitting equation, the linearity is 0.915%; the repeatability error is 1.597%, and the hysteresis is 0.83%, $R^2=0.999$.

2.2.3 Anti-interference ability test of the test system

According to the analysis of the dynamic model of the spray cabinet, the sprayer chassis is not only affected by the lateral force F_y of the medicine liquid, but also by additional longitudinal force F_x and torque M_x , M_y of the medicine liquid, as well as the liquid gravity. To ensure the accuracy of the lateral force measurement sensor in measuring the lateral force F_y of the medicine cabinet, it is necessary to test the interference of forces in other directions with the lateral force sensor. Due to the cloth and group bridge mode of the lateral force measurement sensor in section 2.1, it will shield the interference of the torques M_x and M_y . Therefore, the ability of the lateral force measurement sensor to resist the longitudinal force F_x and gravity interference is only verified here.

The output voltage value of the lateral force measurement sensor is loaded and unloaded along the longitudinal ($\pm x$ direction) to the lateral force measurement sensor. The test was repeated three times, and the average value of the absolute measured bridge output voltage was calculated. The data are shown in Table 3.

Table 3

Average of absolute values of the longitudinal and transverse loading

Calibration weight / kg	Average / mv of the absolute lateral output voltage	Average / mv of the absolute longitudinal output voltage	Longitudinal and transverse output voltage ratio / %
0	5	1	33.3
30	227	13	5.7
60	436	29	6.7
90	667	41	6.1
120	884	55	6.2
150	1124	71	6.3

For charging and discharging, the output voltage of the force-sensitive element is measured. The test is repeated three times, and the average value of the output voltage is calculated. The data are shown in Table 4.

Table 4

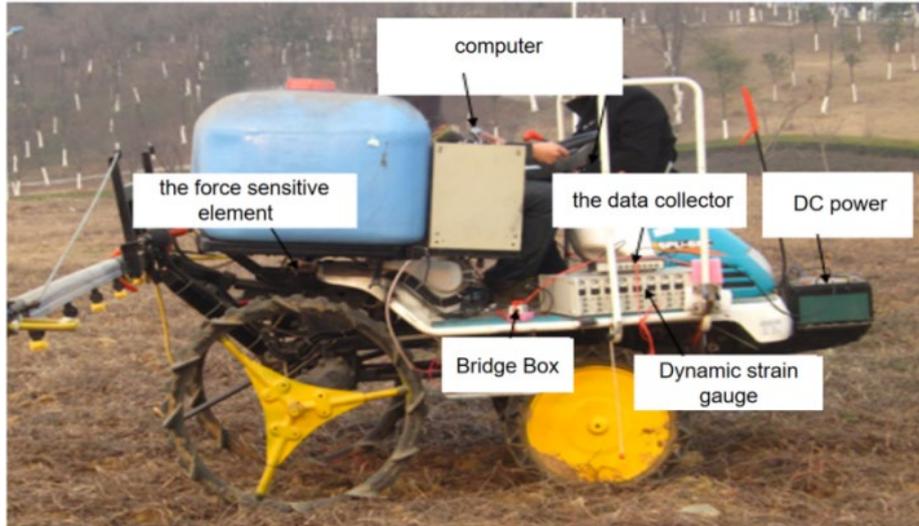
Contribution of the liquid gravity to the output voltage of the force-sensitive element

The amount of fluid added / L	0	100	200	300	400	500	
Output voltage average value / mv	loading	0	-12	-39	-64	-104	-128
	unload	-1	-15	-38	-65	-105	-126

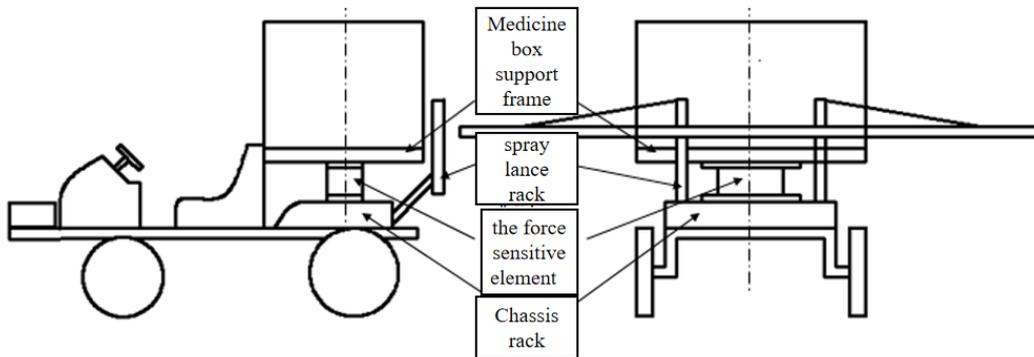
At a water addition of 500L, the z-direction force contributes a maximum of 128mv to the output voltage of the measurement bridge. Substituting into formula 3, it can be inferred that a y-direction load of 175 N will generate circuit voltage. Combined with the field test data in Table 7, the bridge output voltage value of the liquid shaking transverse force is much greater than that in Table 4. This indicates that the lateral force measurement sensor can shield the interference of liquid gravity. Based on the above analysis, it is considered that the force-sensitive element can shield the interference during the lateral force measurement of the medicine cabinet.

2.3 Field Experiment with Lateral Shaking of the Sprayer Water Tank

The experimental prototype used 3WPJ-500D produced by Suzhou Jiale Plant Protection Technology Co., Ltd. The main parameters are shown in Table 5. In Zhenjiang, Jiangsu Province, a 100m×200m vacant field and a first vegetable phase of crops were selected as the test site. The connection mode and parameter settings of each component in the measurement system are consistent with Section 2. The dynamic strain meter and the data collector were fixed to the right side of the sprayer through a fiber rope. To reduce the influence of vibration, the cushion isolation material was added between the dynamic strain meter and the sprayer. The lateral force measurement sensor was installed directly below the support frame of the medicine cabinet through bolt connection. Each bolt gives certain prestress. The lateral force measurement sensor hanged the medicine cabinet, so that the medicine cabinet was no longer connected to the walking chassis frame of the sprayer. The arrangement of the measuring device is shown in Fig. 3.



(a) Site of the test system



(b) Arrangement diagram of measuring Lateral force measurement sensor

Fig. 3 Field test of lateral force of liquid sloshing in sprayer tank

Table 5

Main technical parameters of spray rod sprayer

Parameters	Numeric values	Parameters	Numeric values
Tank capacity / L	500	Tread / m	1.2
Spraying swath / m	11.8	Wheel base / m	1.3
Net mass / kg	300	Engine power / kw	10.5

Since the main working condition of the sprayer is straight and smooth driving, the transverse vibration force of the spray medicine cabinet under straight driving was measured. The test factor level of the sprayer is shown in Table 6. The driving speed of each gear was calibrated before the test. The liquid added in the test process was clear water. In the complete test, the sprayer in III Drive (4.82 km/h) was tested three times at 500L. After each experiment, when the medication stabilized, the automatic balancing function of the dynamic strain gauge was used to re-level the strain measurement bridge.

Table 6

Test factors and levels of lateral force of medicine fluid			
Driving conditions	Factor horizontal	The amount of fluid added / L	Driving speed gear / km/h
Straight line	1	0	I /2.61
	2	100	II /3.42
	3	200	III /4.82
	4	300	—
	5	400	—
	6	500	—

3. Results and Analysis

The lateral force of liquid shaking in the medicine cabinet is random with an alternating load. Due to space limitations, only the results of III Test at speed (4.82 km/h) are shown in Fig. 4. The peak transverse force of liquid shaking in the medicine cabinet was random. Due to random excitation of the field road, the additional transverse force peak of liquid shaking also occurs randomly. As shown in Table 7, the maximum lateral force of liquid shaking in the medicine cabinet appears in the sprayer in III test was at the speed of gear (4.82 km/h), and the fluid volume was 500L. The maximum lateral force of the medicine box was -1540N, which is equivalent to 19.25% of the full load weight of the sprayer.

When the liquid volume of the medicine cabinet was 0L, due to the weight of the water tank support frame and the medicine cabinet, the force sensitivity element will have a certain output under the three-driving speed of the sprayer. However, it is far lower than the output of other processing levels. As shown in Fig. 5, the RMS value of the shaking lateral force is 42N, 46N and 61N, respectively.

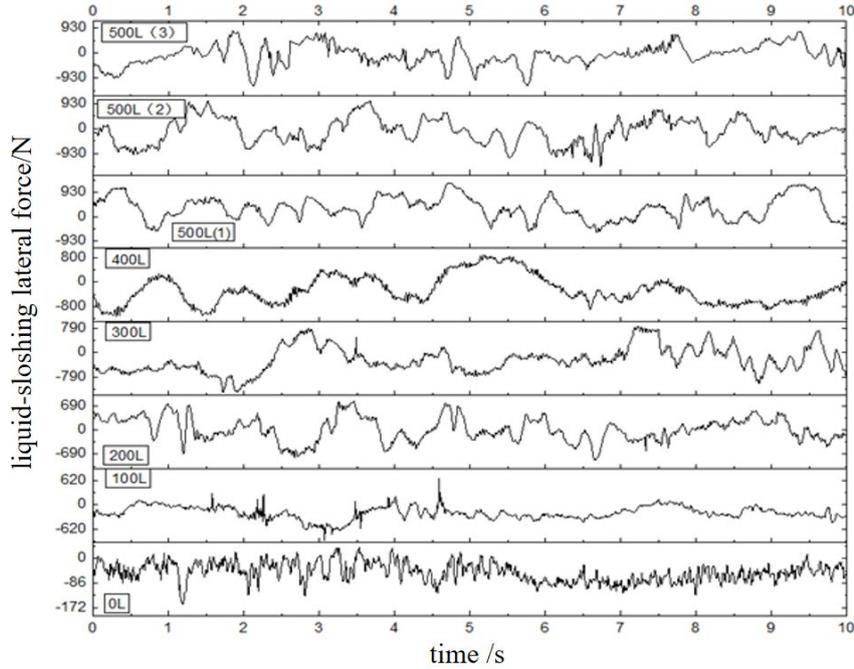


Fig. 4 III Shigear (4.82 km/h)

Table 7

Speed / gear / km/h		Maximum peak of lateral force / N							
		The amount of fluid added / L							
		0	100	200	300	400	500		
I/2.61	crest value	32	269	783	1194	1011	949		
	least value	-78	-706	-798	-607	-622	-1018		
II/3.42	crest value	13	516	754	1250	965	1345		
	least value	-64	-466	-469	-1347	-1341	-1142		
III/4.82	crest value	45	773	833	850	998	1493	1351	1171
	least value	-162	-920	-898	-1268	-1209	-672	-1540	-1330

Although the peak of the lateral force in the medicine cabinet appeared randomly, the larger the walking speed, the greater the fluid volume, and the greater the lateral force. To further understand the relationship between the lateral force of liquid shaking, and the fluid volume and the driving speed, the lateral root mean square value of each test is achieved as follows:

$$RMS(F_y) = \left[\frac{1}{T} \int_0^T F_y^2(t) dt \right]^{\frac{1}{2}} \quad (4)$$

where F_y is the lateral force (N), and T is the data acquisition time (s).

The calculation results are shown in Fig. 5. It can be seen that the increase in the driving speed of the sprayer will increase the lateral force in the medicine cabinet. When the fluid volume is greater than 200L, increasing the driving speed of the sprayer will make the medicine box increase significantly.

An increase in the fluid volume will also increase the lateral force of the medicine fluid. However, when the driving speed is constant, further increase in the fluid volume will result in a diminishing lateral force of the medicine box. Specifically, at driving speed I (2.61 km/h) and speed II (3.42 km/h), the lateral sloshing force no longer increases significantly once the fluid volume exceeded 300 L. Similarly, at speed III (4.82 km/h), the increase in the lateral force also became less pronounced after the fluid volume exceeded 400 L.

The driving speed and fluid volume will affect the lateral force of medicine liquid. If the driving speed of the sprayer was certain, after the fluid volume increased to a certain value, the increase of fluid will not result in an increase in the lateral force of the medicine box. This indicates that although the fluid volume increases, the quality of the fluid involved in wobbly does not increase. If the driving speed increases the liquid mass of the sprayer, the lateral force in the medicine cabinet will also increase. If the driving speed of the spray increases from gear II (3.42km/h) to gear III (4.82km/h), when the liquid volume increased from 300L to 400L, the lateral force of liquid shaking in the medicine cabinet increased significantly.

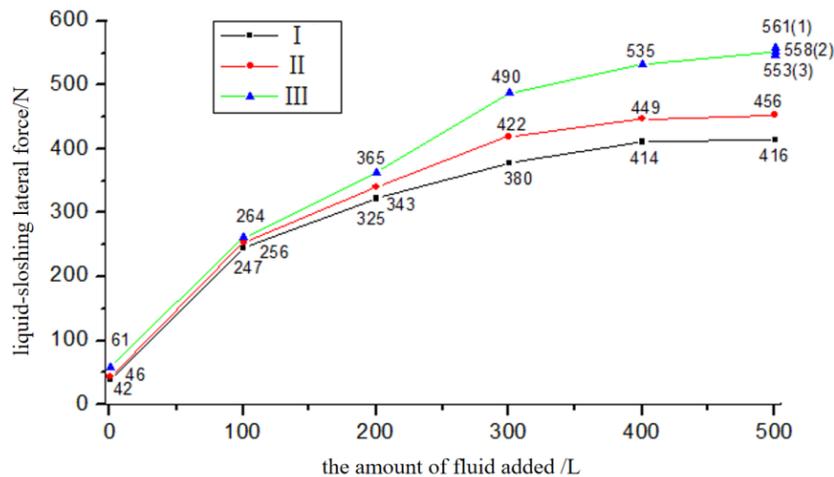


Fig. 7 Average value of lateral force of liquid shaking in the medicine cabinet under different working conditions

4. Conclusion

(1) A lateral force measurement sensor was designed to measure the lateral force of the liquid tank of the sprayer. The lateral force of sprayer liquid in field operation was an alternating load with a maximum amplitude of 1540N, which is equivalent to 19.25% of the total weight of the sprayer. Therefore, this alternating load will fatigue the sprayer and affect the service of the sprayer. Therefore, in the design process of the sprayer, the load generated by liquid shaking of the medicine cabinet should be considered;

(2) The fluid volume of the medicine tank and the driving speed of the sprayer will affect the lateral force of the water tank. Increasing the speed will result in an increase in the lateral force of fluid shaking in the medicine cabinet, especially when the fluid volume accounts for 60%-80% of the whole medicine cabinet capacity. When the fluid volume exceeded 80% of the capacity of the medicine cabinet, although the total liquid mass increased, the liquid involved in the lateral shaking did not increase. Therefore, the lateral force of liquid shaking in the medicine cabinet did not increase significantly;

(3) In the field operation, the shaking of the sprayer cabinet will be stimulated to generate additional lateral force, which will affect the movement of the sprayer. Therefore, it is necessary to further study the influence of the lateral force of cabinet shaking on the movement of spray.

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REFERENCES

- [1] *Speelman, L., & Jansen, J.W.*, "The effect of spray-boom movement on the liquid distribution of field crop sprayers", *Journal of Agricultural Engineering Research*, **Vol. 19**, no.2, 1974, pp. 117-129. [https://doi.org/10.1016/0021-8634\(74\)90027-4](https://doi.org/10.1016/0021-8634(74)90027-4)
- [2] *Jeon, H.Y., Womac, A.R., & Gunn, J.*, "Sprayer boom dynamic effects on application uniformity", *Transactions of the ASAE*, **Vol. 47**, no.3, 2004, pp. 647-658. <https://doi.org/10.13031/2013.16094>
- [3] *Love, J.S., & Tait, M.J.*, "Equivalent mechanical model for tuned liquid damper of complex tank geometry coupled to a 2D structure", *Structural Control & Health Monitoring*, **Vol. 21**, no. 1, 2014, pp. 43-60. <https://doi.org/10.1002/stc.1548>
- [4] *Shi, L., Xia, J.J., & Lu, J.*, "Analysis on Dynamic Characteristics of Liquid Sloshing in Tank of Dangerous Chemical Vehicles" (In Chinese), *Journal of Huaiyin Institute of Technology*, **Vol. 31**, no.1, 2022, pp. 6-20. <https://doi.org/10.3969/j.issn.1009-7961.2022.01.003>
- [5] *Hasheminejad, S.M., Mohammadi, M.M., & Jamalpoor, A.*, "Hydroelastic modeling and active control of transient sloshing in a three-dimensional rectangular floating roof tank", *Journal of Sound and Vibration*, **Vol. 470**, 2020, pp. 115146. <https://doi.org/10.1016/j.jsv.2019.115146>

- [6] Wei, L., Liu, H., Chen, H., & Zhao, Z., "Finite element analysis of cross section of TBR tire", *Mechanics of Advanced Materials and Structures*, **Vol. 27**, no. 17, 2020, pp. 1509-1517. <https://doi.org/10.1080/15376494.2018.1517911>
- [7] Fan, X., Hu, Z., & Zheng, X., "Research on influence of tank sloshing on ship motion response under different wavelengths", *Applied Sciences*, **Vol. 12**, no. 17, 2022, pp. 8647. <https://doi.org/10.3390/app12178647>
- [8] Zhang, E., Zhu, W., & Wang, L., "Influencing analysis of different baffle factors on oil liquid sloshing in automobile fuel tank", *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*, **Vol. 234**, no. 13, 2020, pp. 3180-3193. <https://doi.org/10.1177/0954407020919584>
- [9] Zhang, W., Cheng, W., & Gai, W., "Hazardous chemicals road transportation accidents and the corresponding evacuation events from 2012 to 2020 in China: a review", *International Journal of Environmental Research and Public Health*, **Vol. 19**, no. 22, 2022, pp. 15182. <https://doi.org/10.3390/ijerph192215182>
- [10] Jin, X., Tang, J., Tang, X., Mi, S., Wu, J., Liu, M., & Huang, Z., "Effect of viscosity on sloshing in a rectangular tank with intermediate liquid depth", *Experimental Thermal and Fluid Science*, **Vol. 118**, 2020, pp. 110148. <https://doi.org/10.1016/j.expthermflusci.2020.110148>
- [11] Kolaei, A., Rakheja, S., & Richard, M.J., "Coupled multimodal fluid-vehicle model for analysis of anti-slosh effectiveness of longitudinal baffles in a partially-filled tank vehicle", *Journal of Fluids and Structures*, **Vol. 70**, 2017, pp. 519-536. <https://doi.org/10.1016/j.jfluidstructs.2017.02.012>
- [12] Zheng, J., Han, X., Guo, H., Hou, J., & Xue, X., "Moment Induced by Liquid Sloshing in Rectangular Sprayer Tank under Harmonic Excitation" (In Chinese), *Journal of Agricultural Mechanization Research*, **Vol. 44**, no. 2, 2022, pp. 143-148. <https://doi.org/10.3969/j.issn.1003-188X.2022.02.025>
- [13] Ren, Y., Li, X., Zheng, X., & Wang, J., "Accurate kinetic modeling of the liquid tank truck and its roll stability" (In Chinese), *Journal of Shanghai Jiao Tong University*, **Vol. 54**, no. 3, 2020, pp. 312-321. <https://doi.org/10.16183/j.cnki.jsjtu.2020.03.011>
- [14] Chen, Y., Zhang, S., Mao, E., Du, Y., Chen, J., & Yang, S., "Height stability control of a large sprayer body based on air suspension using the sliding mode approach", *Information Processing in Agriculture*, **Vol. 7**, no. 1, 2020, pp. 20-29. <https://doi.org/10.1016/j.inpa.2019.06.003>
- [15] Yin, X., An, J., Wang, X., Wang, Y., Li, J., & Jin, C., "Design and Test of Automatic Beam Leveling System for High-clearance Sprayer" (In Chinese), *Transactions of the Chinese Society for Agricultural Machinery*, **Vol. 53**, no. 2, 2022, pp. 98-105, 115. <https://doi.org/10.6041/j.issn.1000-1298.2022.02.010>
- [16] Qu, T., Wang, A., & Zhang, M., "Experimental study on vertical oscillation forces of air cooling fan system in running state" (In Chinese), *Journal of Vibration and Shock*, **Vol. 32**, no. 10, 2013, pp. 74-79. <https://doi.org/10.3969/j.issn.1000-3835.2013.10.014>
- [17] Van, N.N., Matsuo, T., Koumoto, T., & Inaba, S., "Transducers for measuring dynamic axle load of farm tractor", *Bulletin of the Faculty of Agriculture, Saga University, Japan*, **Vol. 94**, 2009, pp. 23-25.
- [18] Chen, G., Ju, N., Yang, F., & Li, J., "Monitoring system for vehicle overloading base on paste-type strain sensor" (In Chinese), *Journal of Beijing University of Aeronautics and Astronautics*, **Vol. 37**, no. 4, 2011, pp. 409-414. <https://doi.org/10.13700/j.bh.1001-5965.2011.04.009>
- [19] Sun, Z., Chen, J., Wu, Y., & Xie, Q., "Indirect measurement method for wheel axle lateral force based on KF-LSTM" (In Chinese), *Journal of Vibration and Shock*, **Vol. 43**, no. 13, 2024, pp. 254-267. <https://doi.org/10.13465/j.cnki.jvs.2024.13.028>