



Basic Research on Man-Machine System in Agricultural Machinery (IV) : Factors Influencing upon the Performances of Human Operator's Steady State Response in the Pursui...

Okamoto, Tsuguo

Nishimura, Isao

(Citation)

神戸大学農学部研究報告, 12(2):239-246

(Issue Date)

1977

(Resource Type)

departmental bulletin paper

(Version)

Version of Record

(JaLCD0I)

<https://doi.org/10.24546/00228540>

(URL)

<https://hdl.handle.net/20.500.14094/00228540>



BASIC RESEARCH ON MAN-MACHINE SYSTEM IN AGRICULTURAL MACHINERY

IV. Factors Influencing upon the Performances of Human Operator's Steady State Response in the Pursuit Tracking System*

Tsuguo OKAMOTO** and Isao NISHIMURA**

(Received for Publication on August 10, 1976)

Abstract

The performance of a manual control system could be influenced by the kind of the manipulator, its manipulating sensitivity, the control resistance and the property of input signal. In this paper the characteristics of the pursuit tracking tasks to sinusoidal inputs were experimentally studied.

The results obtained from this study are summarized as follows.

- 1) The results of the harmonic analysis about output wave form indicated that the harmonic coefficients of fundamentals were distinguished, but the ones of other higher order harmonics were smaller than 5 percent of the fundamentals.
- 2) There was a significant difference in fundamental coefficients between the input frequencies. A highly significant scatter difference of fundamental coefficients was found between the input frequencies.
- 3) The effect of the phase shift between the fundamental phase and the input was not statistically significant. The input frequency had a significant effect on the scatter of phase shift. It increased with an increase in input frequency.
- 4) The effects of the input frequencies both on the mean absolute error and on the scatter of control error were highly significant. The higher the input frequency, the greater the control error and the scatter of control error.
- 5) There was a highly significant error power difference between the input frequencies. The higher the input frequency, the larger the error power.
- 6) The frequency at which the error power spectral density was the greatest agreed with the input. The manipulated gains made a difference between the effects of the input frequencies on the peak value of the normalized error power spectral density $S(f_0)$.

I. Introduction

Regarding machine operations as the man-machine system, the work may be affected by the matching between the operator and the machine as well as by the performance capabilities of machine. To design the safe and manageable machine for operators, it is necessary to do the investi-

gation of the human controllability and the optimization of the matching between the operator and the machine. The performance of the manual control system could be influenced by the kind of the manipulator, its manipulating sensitivity, the control resistance, and the input property. In this paper, the characteristics of the pursuit tracking tasks to sinusoidal inputs were experimentally studied and the factors influencing on the performance of the control system will be discussed.

* This report was presented at the annual meeting of the Society of Agricultural Machinery of Japan, Kagoshima, April, 1976.

** Laboratory of Farm Equipments and Machinery

II. Apparatus and Procedure

An operator was seated on a classroom type chair on which a right hand grip-stick 70 cm in length was mounted. He did pursuit tracking tasks of setting the follower spot to the target spot on the cathode-ray tube (CRT) screen by the stick which the follower displacement on the screen was in proportion to. The size of the CRT used to display in this experiment was 10.16×12.70 cm viewing window. In observing the pursuit tracking, two bright dots 0.15 cm in diameter for the target and the follower were displayed and presented to the operator. Two bright dots could move up and down without lateral sweep. When the operator pulled the stick toward him, the follower dot moved upward on the CRT screen. A 50 cm nominal eye-to-display distance was utilized throughout the experiments.

As the input signals, sinusoidal wave forms 2.54 cm in the amplitude were given to the operator. Their input frequencies were set up in five grades at every 0.1 Hz from 0.1 Hz to 0.5 Hz. The displacement of the hand grip of the stick was transformed into proportional voltage by means of a potentiometer and it was amplified,

then displayed on the screen as the displacement of follower dot. Setting the degree of amplification three grades were used in the manipulated gain which was defined as the ratio of the displacement of displayed dot to the displacement of hand grip. Those were in 0.2, 0.5, and 1.0 cm/cm respectively.

The stick was given horizontally forward tension by the coil spring. As the operator pulled the stick toward him, the control resistance to him increased. The control resistance was taken 5.5 kg at the handgrip where the follower was at the origine. The apparent stiffness at the handgrip was 0.503 kg/cm. Besides this elastic resistance, the hand stick was given the disturbance of sinusoidal resistance with the amplitude, 1.51 kg of which the frequency conformed to the input signal. Then, the phase difference between the input and the disturbance was set up at the angle of 0° or 180°, and the effect of the disturbance on control performance was measured.

The experiments were done on an experimental planning method of the completely randomized, 3 way classification, 1 observation per cell model. The sources of variation were the input sinusoidal frequencies, the manipulated gains, and the phase

Table 1. Analysis of variance for wave forms

Source of variation	df	Harmonic coefficient of fundamental			Standard deviation of fundamental coefficient			Standard deviation of fundamental phase shift		
		ms	F	ρ	ms	F	ρ	ms	F	ρ
Disturbance phase (A)	1	0.200	0.21		0.27	0.4		6.08	1.5	
Manipulated gain (B)	2	0.646	0.68		9.51	1.4		4.10	1.0	
Input frequency (C)	4	5.394	5.64*	43.7	94.74	14.1**	54.5	24.71	6.0*	48.2
A × B	2	1.306	1.37		12.93	1.9		5.30	1.3	
A × C	4	0.443	0.46		11.06	1.7		2.36	0.6	
B × C	8	0.850	0.89		12.64	1.9		1.56	0.4	
Error	8	0.957		56.3	6.71		45.5			51.8

* Indicates significance at the 0.05 level of significance.

** Indicates significance at the 0.01 level of significance.

ρ Determination coefficient (%)

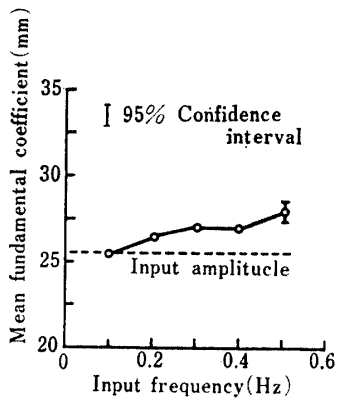


Fig. 1. Effect of the input frequencies on the fundamental coefficient.

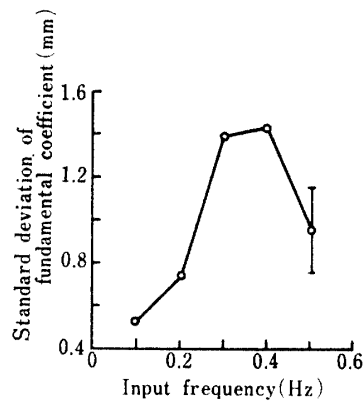


Fig. 2. Effect of the input frequencies on the scatter of fundamental coefficients.

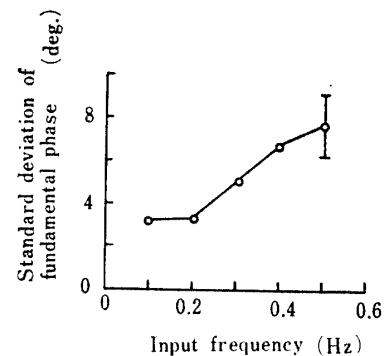


Fig. 3. Effect of the input frequencies on the scatter of fundamental phase.

shifts of disturbance. The subject of a twenty three-year-old student was utilized throughout the experiments. Prior to the formal tracking runs, the subject was allowed considerable practice with the pursuit tracking tasks to keep out of the effect of learning behavior. He took a rest satisfactorily after every trial. Each trial of the pursuit tracking task was run during twenty sinusoidal cycles and was recorded on an electromagnetic oscillograph. The ten cycles data of them was chosen as the subject to the analysis.

III. Results and Discussion

1. Wave forms of the responses

As the operator became skillful in the manual control, his responses had nearly a certain mode^{2,3}. On sinusoidal pursuit tracking task the operator's output wave forms were not always sinusoidal, but could be regarded as periodic functions approximately in steady state.

The results of the harmonic analysis on output wave form indicated that the harmonic coefficients of fundamentals were distinguished, but the ones of other higher order harmonics were smaller than 5 percent of the fundamentals. Table 1 presents the results of analysis of variance for the average of fundamental harmonic coefficients in a trial. The data presented in Table 1 indicated that the factor of input frequencies had a significant effect on the

average of fundamental coefficient at the 5 percent level of significance. There was a significant difference in fundamental coefficient between the input frequencies as shown in Fig. 1, which indicated an effect of the input on the output wave form. The higher the input frequency, the larger the fundamental amplitude of the output wave. The velocity amplitude of the sinusoidal input increased with the input frequency, so that the operator over steered the stick outside at the turn of a target. It is assumed that because of the increase in overshooting, the fundamental amplitude increased with the input frequency.

The analysis of variance for the standard deviation of fundamental coefficients was used to estimate the control stability. The result of the analysis was presented in Table 1 and was shown in Fig. 2 graphically. A highly significant difference was found between the input frequencies. From Fig. 2, the scatter of fundamental coefficients seemed to be great at 0.3 and 0.4 Hz. It is known that the operator could do a program control with a feedback loop on the low target speed of stationary input, but the one with an open loop on the high^{1,5}. Although we cannot definitely conclude this, it is assumed that the critical input frequency between both control modes was nearly 0.3 or 0.4 Hz, so that the scatter of amplitude was great. More detailed experimental research is required.

The analysis of variance for the phase

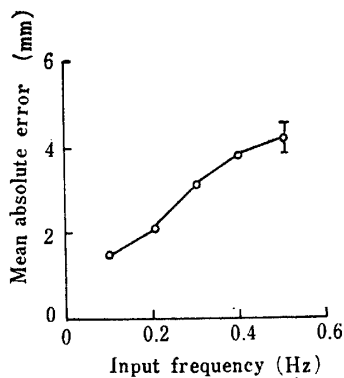


Fig. 4. Effect of the input frequencies on the mean absolute error.

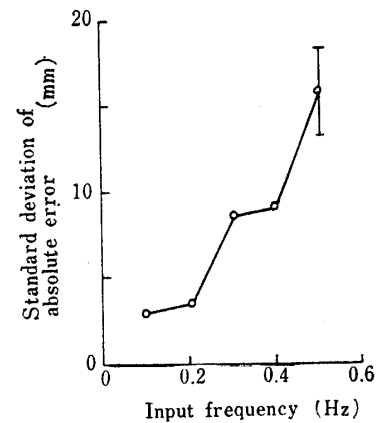


Fig. 5. Effect of the input frequencies on the scatter of absolute error.

difference between the fundamental phase and the input indicated that no factors were statistically significant. The average of the phase shifts was the phase lag of 20.6° , and its standard deviation was 4.23° . Then, the variance of the standard deviation of the phase shifts in a trial of 10 sinusoidal cycles was analyzed. Referring to Table 1, the input frequencies had a significant effect on the scatter of phase shift at the 5 percent level of significance. Fig. 3 shows the effect of the input frequencies on the scatter of fundamental phase. For the open-loop control with high input frequencies the operator could run the tracking task rhythmically setting the follower to the amplitude of the input. As a result it could be the increase of the

phase shift scatter. The operator could do the feedback control on low input frequencies. In comparison with it, on high ones he could control programmatically the tracking system and do the open-loop control to regard the input amplitude as an aim.

2. Control performance

Estimating the control performance, the mean absolute errors between the input and the output were used for the performance index and so those variances were analyzed statistically. The results presented in Table 2 indicated that only the effect of the input frequency was highly significant. It could not be recognizable that there were significant performance differences between

Table 2. Analysis of variance for control performance

Source of variation	df	Mean absolute error			Standard deviation of absolute error		
		ms	F	ρ	ms	F	ρ
Disturbance phase (A)	1	0.033	0.1		1.0	0.1	
Manipulated gain (B)	2	0.299	1.0		3.9	0.2	
Input frequency (C)	4	7.691	26.8**	85.1	162.1	7.8**	67.0
A × B	2	0.194	0.7		16.6	0.8	
A × C	4	0.171	0.6		6.7	0.3	
B × C	8	0.067	0.2		2.7	0.1	
Error	8	0.287		14.9	20.9		33.0

* Indicates significance at the 0.05 level of significance.

** Indicates significance at the 0.01 level of significance.

ρ Determination coefficient (%)

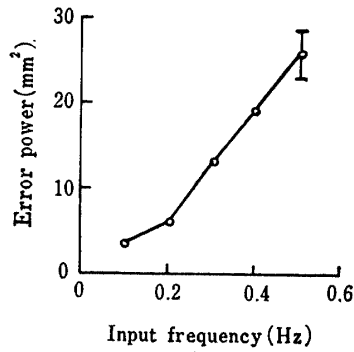


Fig. 6. Effect of the input frequencies on the error power.

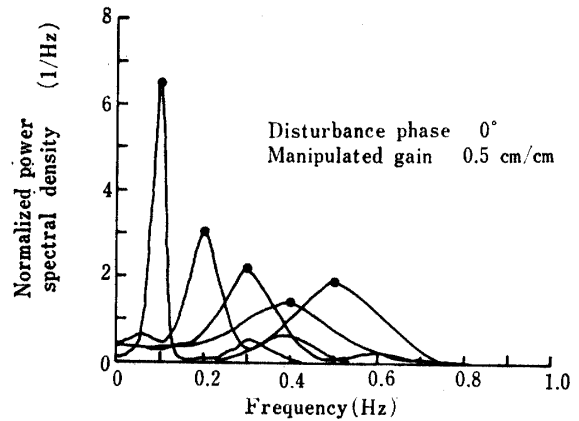


Fig. 7. The typical distributions of normalized error power spectral densities.

the manipulated gains and between the phase shifts of disturbance. It is considered that the operator could adjust adaptively the loop-gain with change of the manipulated gains and optimize the control way.

Fig. 4 shows the effect of the input frequencies of which the determination coefficient was 85 percent on the performance function of mean absolute error. The higher the input frequency, the greater the control error. Therefore, it may be difficult to accurately control the system for high input frequencies.

To estimate the precision of the control, the standard deviations of cyclic averages of the absolute error in a trial were analyzed in much the same way as above. From Table 2, it is evident that only the effect of the input frequencies had a highly signi-

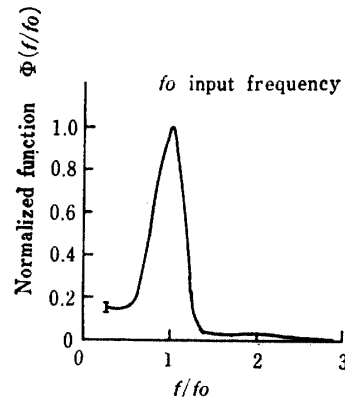


Fig. 8. Normalized function $\Phi(f/f_0)$.

ficant precision difference. Its determination coefficient on the standard deviation of the cyclic absolute errors was 67 percent and the effect is shown in Fig. 5. The higher

Table 3. Analysis of variance for tracking error power

Source of variation	df	Error power			Spectral density $S(f_0)$		
		ms	F	ρ	ms	F	ρ
Disturbance phase (A)	1	0.0	0.0		3.16	8.0*	4.1
Manipulated gain (B)	2	14.0	0.4		3.32	8.4*	8.6
Input frequency (C)	4	511.1	12.8**	77.4	10.37	26.1**	57.7
A × B	2	38.0	1.0		0.02	0.1	
A × C	4	13.7	0.3		0.31	0.8	
B × C	8	2.2	0.1		1.74	4.4*	16.4
Error	8	39.8		22.6	0.40		13.2

* Indicates significance at the 0.05 level of significance.

** Indicates significance at the 0.01 level of significance.

ρ Determination coefficient (%)

the input frequencies, the greater the scatter of control error. It indicates the lowering of the tracking precision with an increase in the input frequency.

At the low input frequency, the operator could make good the program control by using the feed back control jointly, while on the other hand at the high input frequency the moving speed of the target point was faster—the velocity amplitude 16 mm/s at 0.1 Hz and 80mm/s at 0.5 Hz—and it could be impossible to timely do the feed-back control. Consequently, the control error increased and the control stability lowered.

3. Power spectral density of the tracking error

The manual control system which uses a human operator as a system element who makes a complicated response should involve an uncertain response and a non-linear in addition to a linear. Then, to study the fluctuation of the tracking error the power spectral density of the error between the input and the output was calculated.

The analysis of variance for the error power (the variance of error) presents the result in Table 3. The effect of the the input frequencies, one of three factors, was highly significant, and its determination coefficient was 77 percent. There was a highly significant error power difference between the input frequencies as shown in Fig. 6. The higher the input frequency, the larger the error power.

Then, the normalized error power spectral density which indicates the frequency characteristics of tracking error was calculated with the Fourier transformation of the auto-correlation function. The distributions of the power spectral densities shown in Fig. 7 are examples calculated under the condition of the manipulated gain 0.5 cm/cm and the disturbance phase 0°. The frequency where the power spectral density is the greatest agrees generally with the input frequency. Under the other conditions, the same characteristics were observed³⁾.

To characterize the distributions of the

error power spectral densities, it is convenient to introduce a normalized function

$$\phi(f/f_0) = S(f)/S(f_0),$$

where $S(f)$: Normalized power spectral density

f : Frequency, Hz

f_0 : Input frequency, Hz.

As a result of the analysis the function $\phi(f/f_0)$ is shown in Fig. 8 independently of the three factors.

It is useful to adopt the peak value $S(f_0)$ as a parameter to characterize the error power spectral density distributions. Considering the property of a normalized power spectral density that

$$\int_{-\infty}^{\infty} S(f) df = 1,$$

it is possible to find out the relation between the input frequency and the spectral density distribution. As the peak value $S(f_0)$ increases, the rate of the power in the input frequency to the error power increases and the distribution pattern in the shape of an unfolded fan gets sharp. On the contrary, at the low peak value $S(f_0)$ the effect of the power except the input frequency cannot be negligible. Therefore, it is assumed that the linearity of the human operator's response becomes lower.

Investigating the effect of each factor on the distribution of the error power spectral density, the analysis of variance for the peak value $S(f_0)$ was utilized. The result presented in Table 3 indicated that the main effect of the input frequencies was significant at the 1 percent level of significance, the manipulated gains 5 percent and the disturbance phases 5 percent respectively. Besides, the interaction between the input frequencies and the manipulated gains was significant at the 5 percent level.

Fig. 9 shows the main effect of each factor. The higher the input frequency, the lower the peak value $S(f_0)$ which was the normalized error power spectral density at the input frequency. It was found that the linearity of response lowered with an increase in input frequency. The peak value $S(f_0)$ was of the great value at a low input

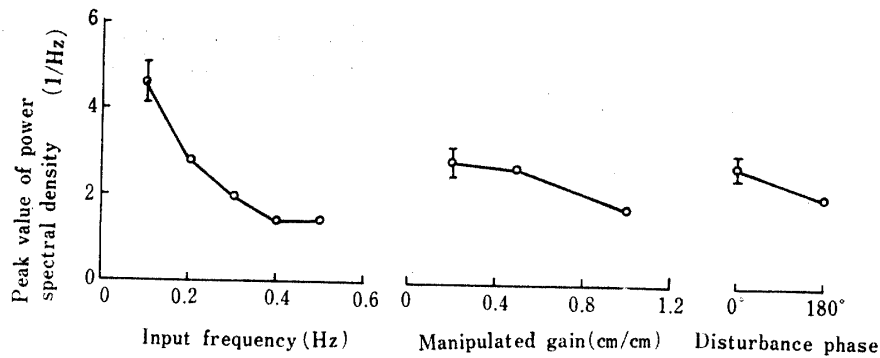


Fig. 9. Main effects of the input frequencies, the manipulated gains, and the disturbance phases on the peak value of normalized error power spectral density.

frequency. It is, therefore, considered that the tracking error was caused mainly by phase shift.

The main effects and the interaction between the input frequencies and the manipulated gains are shown together in Fig. 10, where the manipulated gains made a difference between the effects of the input frequencies on the peak value $S(f_0)$. At a low manipulated gain, 0.2 or 0.5 cm/cm, there was a considerable effect difference between the input frequencies, and the linear component of response increased with a decrease of input frequency. However, the effect of the input frequencies at 1.0 cm/cm in the manipulated gain was negligible on the peak value $S(f_0)$ and the linearity lowered generally.

IV. Conclusions

Based on the analysis of the experimental results obtained, the following conclusions can be made :

1. The results of the harmonic analysis on output wave form indicated that the harmonic coefficients of fundamentals were distinguished, but the ones of other higher order harmonics were smaller than 5 percent of the fundamentals.

2. There was a significant difference in fundamental coefficients between the input frequencies. A highly significant scatter difference of fundamental coefficient was found between the input frequencies.

3. The effect of the phase shift between the fundamental phase and the input was not statistically significant. The input fre-

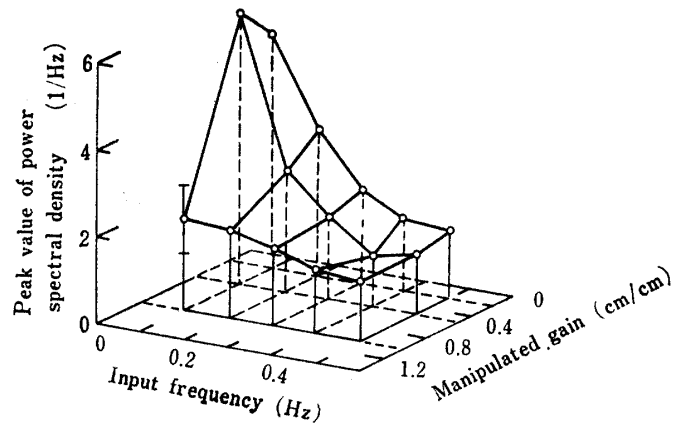


Fig. 10. Interaction between the input frequencies and the manipulated gains on the peak value of normalized error power spectral densities.

quency had a significant effect on the scatter of phase shift. It increased with an increase in input frequency.

4. The effects of the input frequencies on the mean absolute error and on the scatter of control error were both highly significant. The higher the input frequency, the greater the control error and the scatter of control error.

5. There was a highly significant error power difference between the input frequencies. The higher the input frequency, the larger the error power.

6. The frequency where the error power spectral density was the greatest agreed with the input. The manipulated gains made a difference between the effects of the input frequencies on the peak value of the normalized error power spectral density $S(f_0)$.

References

- 1) ITO, K., H. HAYAMI and M. ITO: *Trans. SICE*, **9**, 37—44, 1973.
- 2) OKAMOTO, T. and I. NISHIMURA : *Sci. Rept.* *Fac. Agr. Kobe Univ.*, **11**, 265—270, 1975.
- 3) —, — : *Sci. Rept. Fac. Agr. Kobe Univ.*, **12**, 77—84, 1976.
- 4) —, — : *J. SAMJ*, **37**, 520—525, 1976.
- 5) TSUCHIYA, K. : *J. JAACE*, **12**, 36—43, 1968.

人間—農業機械系に関する基礎的研究

第4報 追跡動作系の定常応答に影響する因子

岡本 嗣 男・西 村 功

要 約

手動制御系の制御特性は、操作器の種類、操作器の感度あるいは操作抵抗力の大小によって影響を受け、さらに目標値入力の特性によっても変わる。本報ではレバーハンドル型の操作器をもった手動制御系の正弦波追跡動作特性を測定し、系の制御成績に影響を与える因子を調べた。

得られた結果を要約すると

- 1) 制御者の出力波形を調和解析した結果、基本波成分の係数が卓越しており、他の高次ハーモニックはその5%以下であった。
- 2) 基本波振幅は入力周波数の影響を受けることが認められた。入力周波数とともに振幅が大きくなる傾向を示した。また入力周波数によって基本波振幅のばらつきに差のあることがわかった。
- 3) 基本波の位相を入力と比較すると、平均位相ずれに有意な効果を与える因子は認められず、平均値 20.6° の位相遅れ、標準偏差 4.23° であった。しかし入力周波数によって位相ずれのばらつきに有意な差のあることが認められた。入力周波数が高くなるにつれてばらつきは大きくなる傾向があった。
- 4) 入力周波数が高くなるにつれて、出力と入力との平均絶対誤差および絶対誤差のばらつきは共に増大する傾向が認められ、高い周波数の入力に対しては制御の正確さも精密さも共に低下することを示している。
- 5) 制御誤差の変動パワーは入力周波数の影響が顕著であり、比例の関係が認められた。
- 6) 制御誤差のパワースペクトル密度が最大となる周波数は入力周波数に一致した。パワースペクトル密度の最大値 $S(f_0)$ は、入力周波数、操作ゲインおよび操作抵抗外乱位相の影響が認められた。