オンオフ制御によるクラブ・ステアリングの自動操向(2)

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ON-OFF CONTROL OF CRAB-STEERING (II)

— Automatic Steering Experiments —

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Abstract

Using constructed crab-steering vehicle, automatic steering system was composed and experiments were carried out. The white stripe drawn on asphalt surface was set up in various patterns as desired passes for guidance. Tracking error was detected by the system composed by a pair of infrared sensors of reflection type and microcomputer. The lateral position of vehicle is controlled with the output on-off signal of detecting system through hydraulic-driven steering mechanism. Automatic steering experiments were carried out to verify the theoretical analysis on the response to sinusoidal input and to consider the response to ramp-function input as those in practical conditions.

Outlines of Crab-Steering Vehicle and Cnotrol System

Experimental Vehicle The crab-steering vehicle constructed for the studies[1,2,3] was composed by using the front axle assemblies of commercial 4WD-tractor. The all wheels are in same size and driven through a hydrostatic transmission. The steering operation is supported by the steering linkages controlled by electro-hydraulic system. On the flame of the vehicle, a gasoline engine, a hydraulic power unit, some hydraulic valves and an oil tank are mounted. The general view of the vehicle is shown in Fig. 1 The specification of the vehicle is presented in Table 1.

The steering operation is done by on-off electronic signal. When the signal is off, steering is adjusted to the neutral position. When steering signal for either direction is on, steering is done to the direction untill the angle becomes the settled maximum steering angle (MSA). Position control of the hydraulic cylinder operating the steering

Table 1 Specifications of Crab-steering Vehicle

Total Weight	360 kg
Length	1170 mm
Width	810
Height	1080
Wheel Base	710
Tread	750
Min. Ground Height	220
Wheel	4.00-10-2PR, 4WD
Engine	Upright, Air-cooling Spark Ignition, Gasoline 8 kW / 3400 rpm
Transmition	Hydro-static
Steering Device	Hydraulic Cylinder + Drag Link
Max. Steering Angle	30°

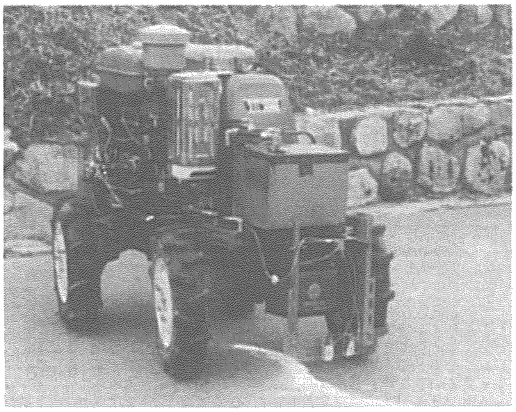

Fig. 1 General View of Crab-steering vihicle

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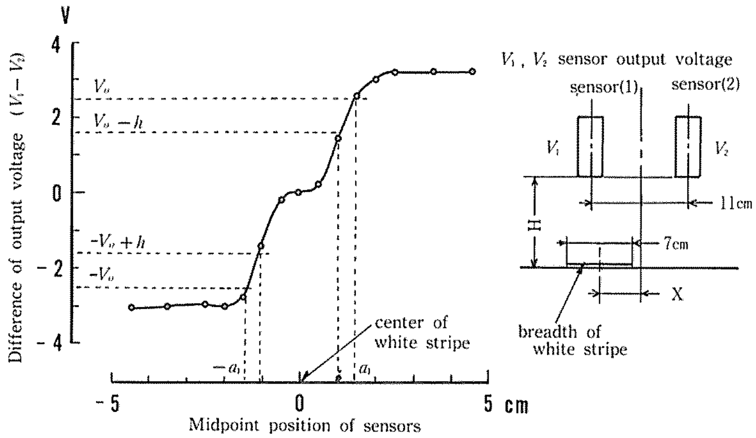
angle is supported by on-off servo-circuit and the feedback of piston displacement detected by a differential transformer. The circuit is composed by differential amplifier and a pair of comparators. Further details are presented in Appendix A.

Automatic Steering System The desired pass to guide the vehicle was the white stripe of 7 cm breadth painted on asphalt-surface. The desired pass was detected by a pair of infra-red sensor of reflection type attached on the vehicle body in downward attitude. Modulated infrared light is transmitted and reflected light is received and demodulated to analog DC signal. A pair of sensors were raid on the flame at a distance that is wider than the stripe breadth. The difference between output voltages of two sensors set at a distance of 11 cm were plotted as shown in Fig. 2. The voltage differences are plotted against the the midpoint positions of two sensors as the distances from the center of white stripe. When sensor (1) is upon the stripe and sensor (2) is far from the stripe as shown in the figure, output voltages of the sensors V_1 and V_2 are high and low respectively and the difference $(V_1 - V_2)$ is positive. When both sensors are at nearly equal distance from the center of the stripe, both output voltages are



Fig, 2 Position vs. Output Voltage of Sensors

Table 2 Conditions of Experiments

Pattern of Desired Pass		MSA */ DBW **
Step (5 cm Height)		5° / 2 cm 10° / 3 cm, 10° / 2 cm 15° / 4 cm, 15° / 3 cm
Sinusoidal Wave L. + Amplitude	1.5 m + 2 cm 1.5 m + 3 cm 1.5 m + 4 cm 1.5 m + 5 cm 2.0 m + 2 cm 2.0 m + 3 cm 2.0 m + 4 cm 2.0 m + 5 cm	5° / 2 cm 10° / 3 cm
Ramp Inclination + Height	3° + 3 cm 3° + 5 cm 5° + 3 cm 5° + 5 cm 8° + 3 cm 8° + 5 cm	5° / 2 cm 10° / 3 cm 15° / 4 cm

* Muximum Steering Angle ** Dead Band Width

nearly equal and the difference is nearly equal to zero. If appropriate voltage levels are settled for the difference, tracking error can be detected as three state signal. When $V_0=2.5$ V and $h=0.8$ V, thershold a_1 and hysteresis a_2 are 1.5 cm and 1 cm respectively. For the easy modification of evaluating program and the accuracy on switching levels setting, microcomputer was employed in detecting system which evaluated the output voltages of two sensors and tracking error signal. The details of I/O circuit of micromputer and evaluating program are presented in Appendix B. The output signal of the I/O circuit as the steering signal is applied on the position control circuit for steering cylinder. The block diagram of steering control system was shown in the previous paper[4].

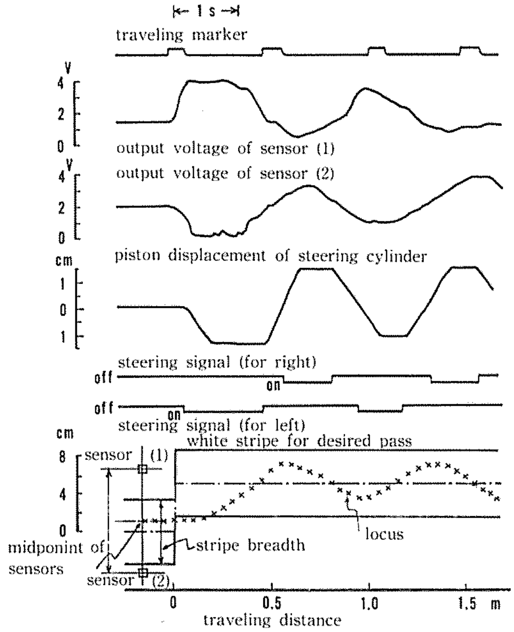


Fig. 3 An Example of System Operating State

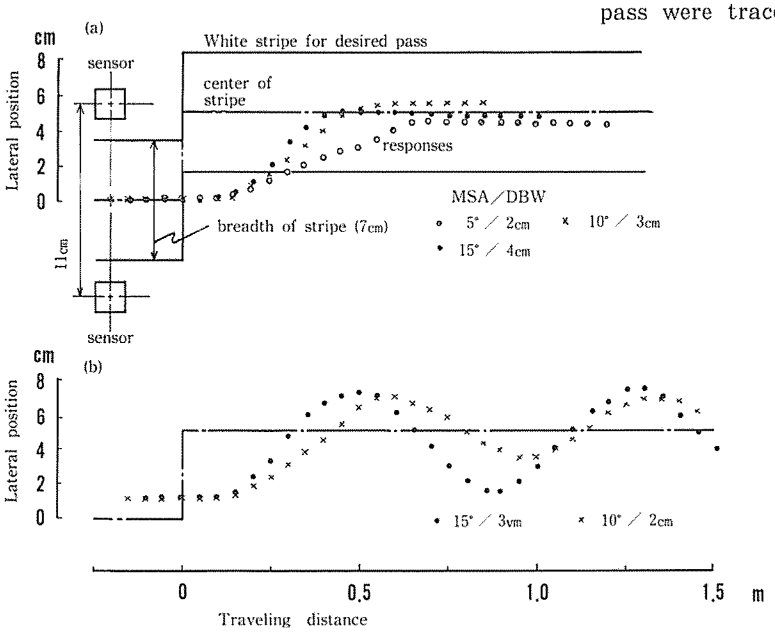


Fig. 4 Response to Step-Function Input

Experimental Procedure

Test runs were carried out on the asphalt-surface to avoid the disturbance caused by roughness or stone upon the ground. White stripe of 7 cm in breadth was painted upon the asphalt surface as desired pass. The locus of guided vehicle was directly drawn on the surface by a chalk attached on the vehicle. The drawn locus and the desired pass were traced and drawn on long tracing paper sheeted on the experimented track.

Experimental conditions are presented in Table 2. Three types of desired pass were presented; step-function, sinusoidal and ramp-function passes. The ramp-function has the pattern such that the onset part of step-function is replaced with ramp segment. The ramp-function pass was designed to the simulation of practical desired pass in the field operation. Experiments were carried out in all combination of conditions cited in left and right columns within each type in the table.

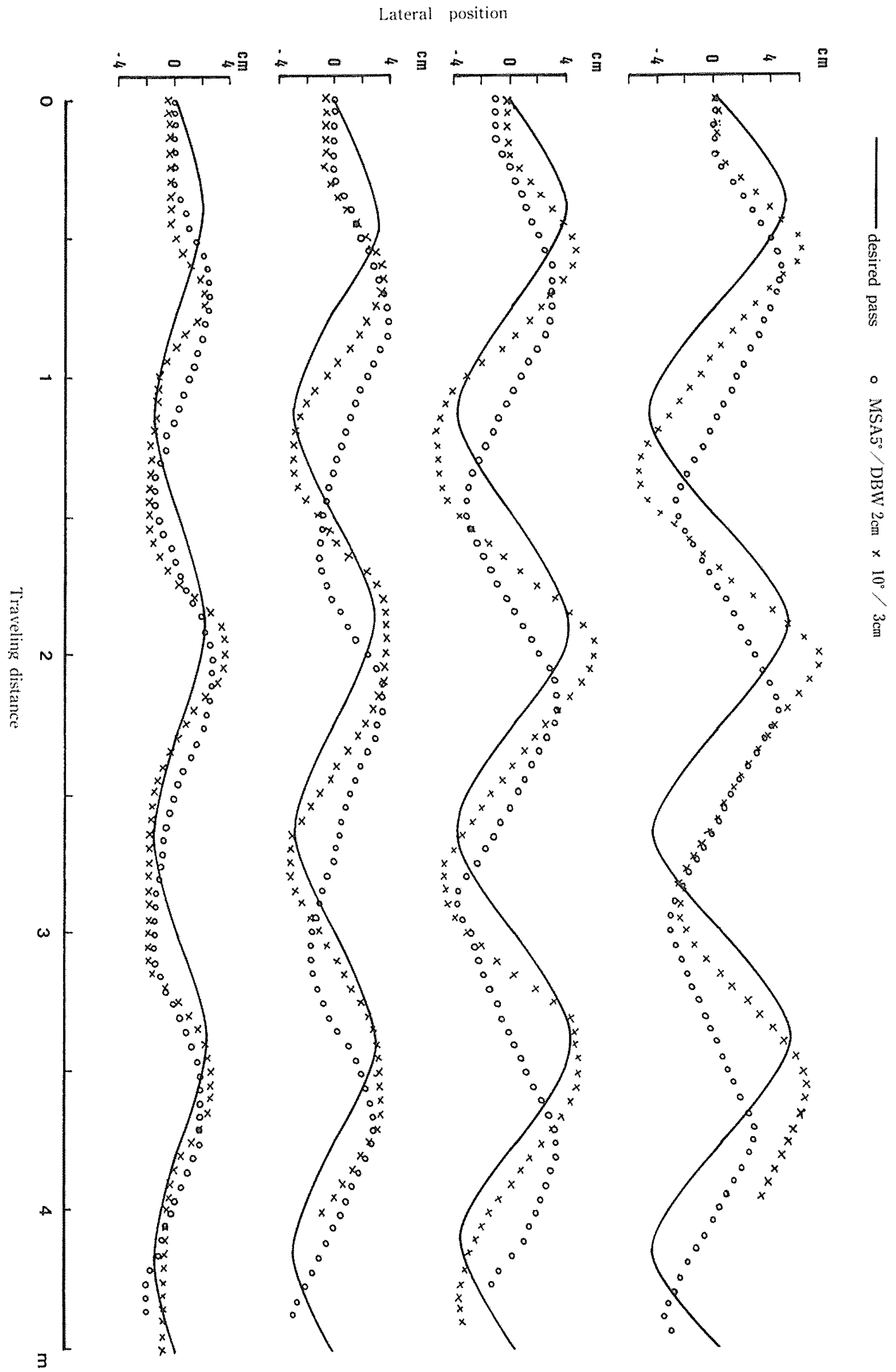


Fig. 5 Response to sinusoidal Input of 1.5m Wavelength

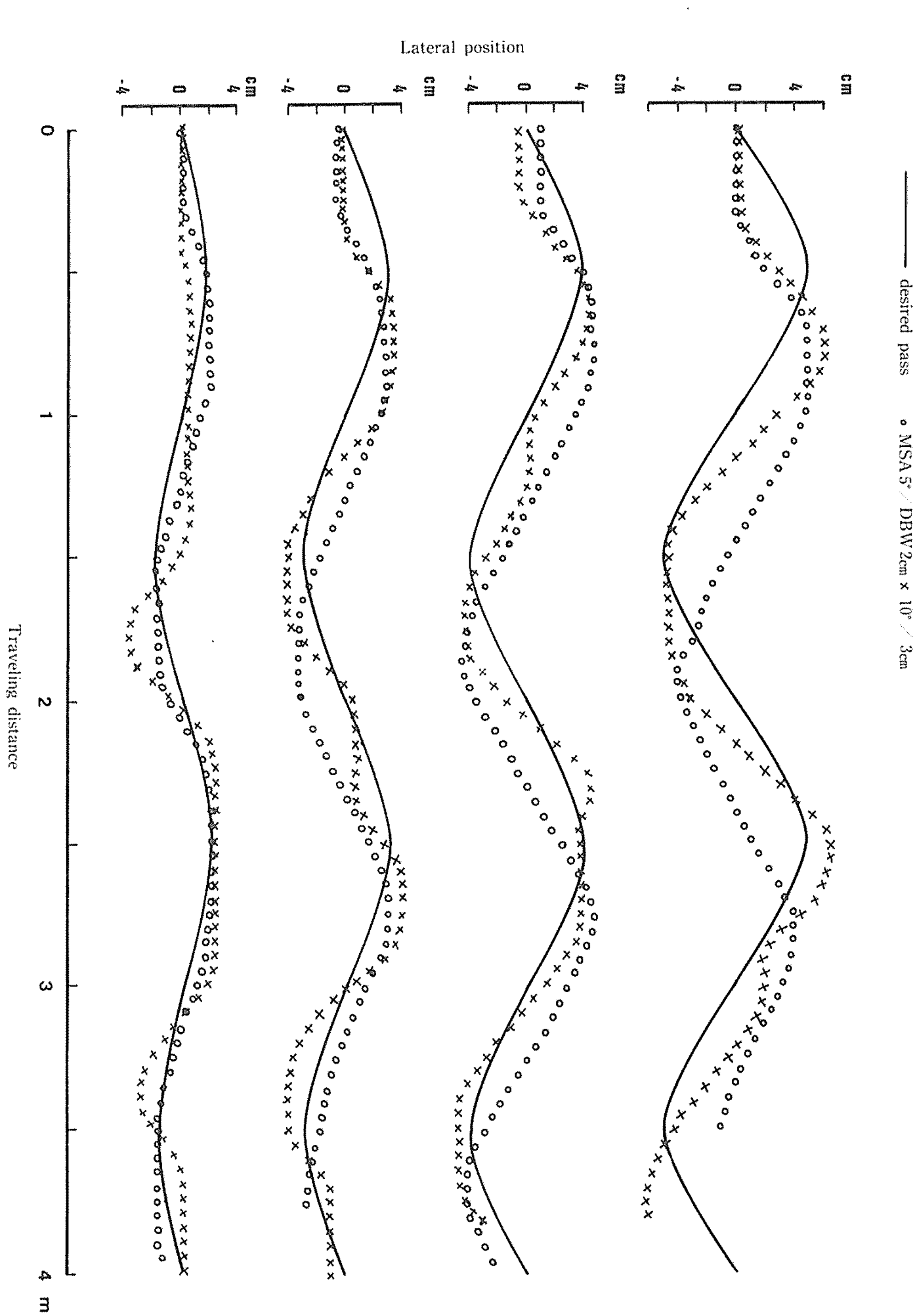


Fig. 6 Response to sinusoidal Input of 2.0m Wavelength

In the conditions of step-function desired pass, experiments in practical field were also carried out. In the field experiments desired pass was drawn with lime and locus of guided vehicle was maked by the notch on the sole of the skid attached on the vehicle. Recording procedure was same method as mentioned above. The traveling velocity was settled at 30 cm/s and the piston speeds of cylinder were at 0.718 (for rightward steering) and 0.680 (for left) rad/s through all experiments.

For the investigation of system operating state, the output voltages of two sensors, steering signals, the piston displacement of steering cylinder (output voltage of differential transformer) and the traveling marker were recorded by using a magnetic tape recorder mounted on the vehicle. Traveling marker was the pulse output of infrared sensor sensing the reflected light by slender columns arrayed in 50 cm distances and parallel direction to traveling.

Results and Discussions

An example of system operating states is shown in Fig. 3. This is the recorded results of system reponse to step-function input in the setting condition of 10° MSA and 2 cm dead band width (DBW) in which limit cycle exists. In the figure the locus of guided vehicle was plotted according to the recorded chart by referring to the traveling marker. Each output voltage of sensor changed after the onset of desired pass. The steering signal became on and the steering cylinder displaced. The lag time between steering signal and piston working was 0.26 s. When the steering angle became the settled MSA, the cylinder displacement was held at its position untill the steering signal became off.

The loci of the vehicle guided to step-function desired pass are shown in Fig. 4. The results shown in (a) were stable and the results in (b) unstable. The theoretical stability presented in the previous paper[4] agreed with the these experimental results. In the field experiments same results as ones on asphalt surface were obtained on the enough flat surface of soil but the disturvance caused by the roughness or stone was observed. At this occasion the yaw angle of the vehicle was usually changed and the longitudinal axle of the vehicle became incline to the desired pass of step-function and the response became after ramp response, therefore a limit cycle exists always and the locus is in same pattern to jerking motion. Thus disturvance is not seldom in practical field traveling, so the deviation of the traveling direction has to be detected and compensated with any method. If the compensation of the traveling direction is not supported, the contral system has to include differential element and detector of the value of tracking error.

The responses to sinuoidal desired passes are shown in Fig. 5 and 6. The results for 1. 5 m wavelength of sinusoidal curve of various amplitude from 2 to 5 cm are in Fig. 5, and for 2.0 m wavelength in Fig. 6. In both figures the results at 5° MSA / 2 cm DBW are plotted by ∘ , and the results at 10° / 3 cm by × . In the responses to the passes of 1.5 m wavelength (Fig. 5), the loci at 5° MSA / 2 cm DBW were obviously stable for the passes of larger amplitude than 4 cm and the locus at 10° / 3 cm was stable for 5 cm in amplitude. In the conditions of the other wavelengths straight part of the loci were observed. In the condition of 2.0 m wavelength (Fig. 6), responses were stable in the condition of 5° MSA / 2 cm DBW for 4 and 5 cm in amplitude, and unstable in the other conditions. In the unstable respons the wavelength of limit cycle was 80 cm (3 rad/s for 30 cm/s traveling velocity) which agreed with theoretically obtained value[4]. From the results shown in Fig. 5 and 6, the stability at each combination of input wavelength and amplitude agreed with the result of theoretical analysis on critical input amplitude presented in the previous paper[4]. If the curvature of practical desired pass in field operation is assumed as the segment of harmonic input, estimated amplitude may be almost plotted under the critical input amplitude (in the limit cycle area) for each wavelength.

The responses to ramp-function input are soown in Fig.7 in which (a) is for 3 cm height of ramp and (b) for 5 cm height. The loci at 5° MSA / 2 cm DBW, 10° / 3 cm and 15° / 4 cm are plotted by the marks as presented in the figure. This function was settled as more practical pattern to the simulation of the desired pass in field operation. The control error area was applied on the practical estimation of these results. The control error area is usually defined at the time interval 0 to ∞ for step response. In this study the error area was extendedly applied on ramp response, as shown in Fig. 8. The variable of integration was replaced to traveling distance and the interval of integration was assumed from onset of ramp to the settling of re-

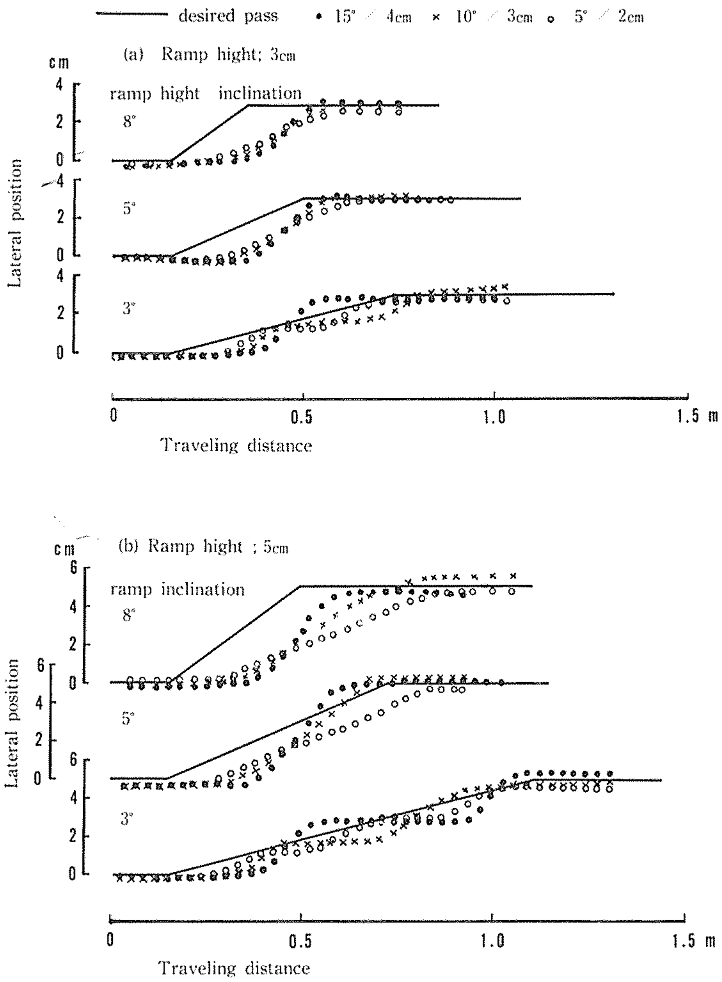


Fig. 7 Response to Ramp-Function Input

sponse for the exclusion of offset.

The relations between MSA and control error area are plotted for the inclination of ramp as parameter in Fig. 9 in which the black plot is for the response with limit cycle. The error area made little difference for the input of 3 cm ramp height and of 5° and 8° inclination. In the response with limit cycle the error area was comparatively small and increased with the increase of MSA. Significant decrease of the error area was seen for the input of 5 cm ramp height and 8° inclination. Thus relation may be agreable from observing the patterns of loci shown in Fig. 7.

If the steering speed is constant, the upper limit of MSA can be decided only from the DBW which is given by the allowable offset as static accuracy. Hence the minimum control error ares is instantly decided for the step response. When the onset part of step-function is replaced to ramp segment, the error area is decided by three factors; ramp height, ramp inclination and MSA. In practical operation in field, the desired pass can be assumed as the aggregation of the parallel straight lines and ramp segments. If each ramp segment in desired pass is enough short, the control error area can be reduced by setting MSA at larger than the inclination of the ramp segment.

Acknowledgment

The author wish to thank Prof. Noboru Kawamura, Professor Emeritus of Kyoto University, who directed author's doctor thesis "Studies on Automatic Steering and Automatic Tillage with Crab-Steering Vehicle" including this paper.

References

1) HORIO, H. *et al: J. Japanese Soc. agric. Machinery*, 43(4), 523-531, 1982 (in Japanese with English summary)
2) HORIO, H. *et al: J. Japanese Soc. agric. Machinery*, 44(3), 423-429, 1982 (in Japanese with English summary)
3) HORIO, H.: *Sci. Rep. Fac. Agr. Kobe Univ.*, 16(1), 245-251, 1984 (in Japanese with English summary)
4) HORIO, H.: *Sci. Rep. Fac. Agr. Kobe Univ.*, 18(2), 187-196, 1989

Appendix A

The servo circuit for position control of steering cylinder is shown in Fig. a. The output voltage of differential tramformer detcting the displacement of steering cylinder is applied on differential amplifier (IC_2) through a buffer amplifier (IC_1). The desired voltage corresponding to MSA is set with reference diode (D_1) and regulated by anglog

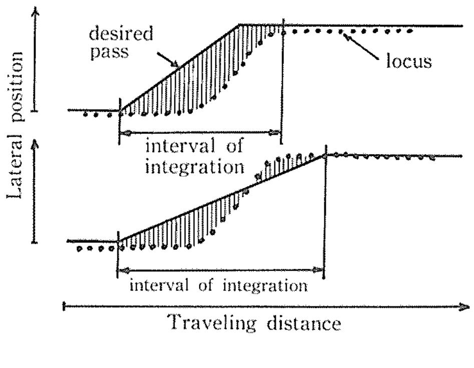


Fig. 8 Culculation of Control Eror Area

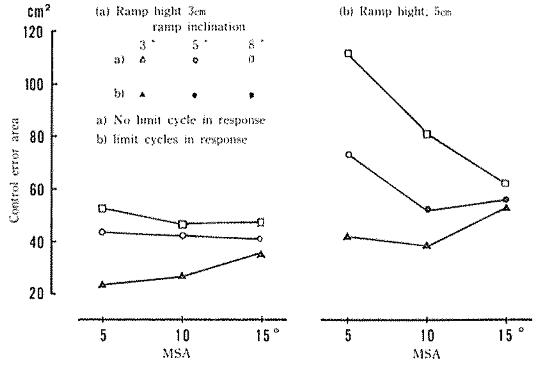


Fig. 9 Control Error Area vs. Maximum Steering Angle (MSA)

switch (IC_5) that is operated by on-off steering signal. The output voltage of differential amplifier is corresponding to the offset between desired and detected steering angle. This offset signal is compared by a pair of comparators ($IC_{3,4}$) of which thresholds are set at the neighbourhood of zero for opposit polarity each other. The output signals of comparators control solenoid vales though level convertor ($Tr_{1,2}$) and booster relays.

When piston displacement of cylinder reaches to desired value, the offset signal becomes less than the threshold and the signal controling solenoid valve becomes off. When steering signal changes to be off, the output of differential amplifier increases for oposit polarity and steering cylinder is controlled to adjast neutral steering.

Appendix B

The I/O circuit of microcomputer is shown in Fig. b. The output voltage of two infrared sensors are selected with multiplexer referred by an adressing signal from a PIA and applied on an AD convertor through a sample-holder amplifier. The computed output signal from PB4, 5 ports is applied on the servo circuisit for position control of steering cylinder. CA1 and PB3 are control lines for data aquisition.

The flow chart of program for computing steering signal is shown in Fig. c in which m is the output of relay element, M is the amplitude of relay output, $r=m/M$, h is the hysteresis width and V_0 is threshold. The output voltages of two sensors V_1, V_2 are evaluated with the equations presented in the figure. The equation $X=X+rh$ is equivalent to hysteresis of relay as explained in Fig. d. Let e be relay input in the figure. The circuit composed by positive feedback of k/M is equivalent to the relay with hysteresis. The variable r is set at the last calcutating step as shown in the lower part of Fig. c.

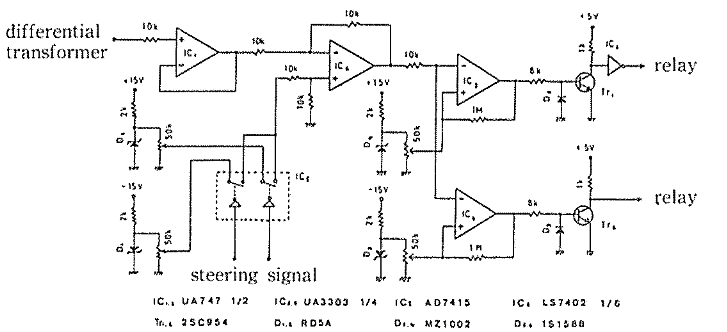


Fig. a Servo circuit for Position Control of Steering Cylinder

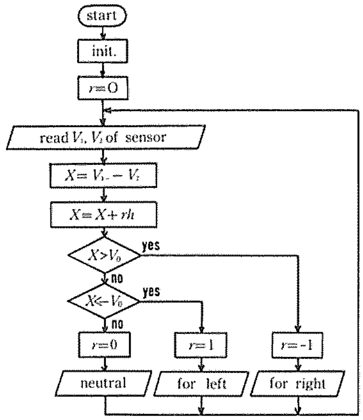


Fig. c Flow Chart of Control Program

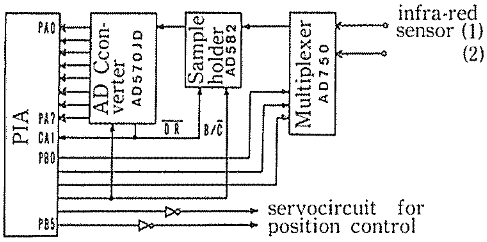


Fig. b I/O Circuit of Microcomputer

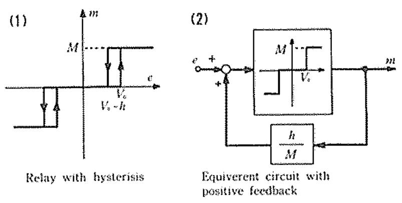


Fig. d Equivalent Circuit of Relay with hysterisis

オンオフ制御によるクラブ・ステアリングの自動換向（Ⅱ）
──自 動 操 向 実 験──

堀 尾 尚 志

要 約

試作したクラブ・ステアリング車を用い、自動操向実験を行なった。アスファルト路面にペイントで描いた白線を目標経路とし、これを1対の反射型赤外線光電センサとマイクロ・コンピュータにより信号を処理しトラッキング・エラーを検出した。自動操向実験は、解析結果を検証するため波長と振幅を変えた正弦波目標経路に対して、また実際の状況を想定してステップ関数の立上り部分をランプに置き代えた形の目標経路に対してそれぞれ行なった。