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AUTOMATIC LEVEL CONTROL OF BULLDOZER BLADE BASED ON FUZZY THEORY

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ABSTRACT

Ground leveling by bulldozer blade should be automatically controlled since the operation is an exhausting work for the bulldozer operator. In this paper, fuzzy control is used for the blade operation in the ground leveling. A series of tests using model bulldozing vehicle are carried out to check the effect of membership functions in the fuzzy control and the vehicle speed. Moreover some tests based on proportional action control are conducted to compare with the results of the fuzzy control tests. As a result, to adjust the membership functions was effective in improving the results of fuzzy control tests, and a distinction between the properties of the two control methods was made clear.

1. INTRODUCTION

Bulldozer is a powerful machine in construction works. One of the works which a bulldozer can do is to level off the ground by the blade equipped in front of the vehicle. This work is difficult because the blade is attached to the front of the bulldozer, which is a little far from the operating room, and because the ground is not so even. There have been a few studies[1)-3)etc.] about the automatic ground leveling. Mostly these works were based on the on-off control or the ordinary feedback control. The results obtained from these studies were to some extent successful, but the accuracy is expected to be more improved. Fuzzy control is one of the possible solutions for the improvement. The fuzzy control has been firstly introduced to a real control problem by Mamdani(1974)[4)]. Since then a number of researchers have also proved the effect of the fuzzy control in complicated systems. In a field of construction engineering, also some papers[5)6)] have already proposed.

Membership functions play an important role on the fuzzy control since fuzzy linguistic information is expressed by these ones. Accordingly, the improvement of operator's skill would be represented by the change of the membership functions in the fuzzy control. The targets of this study are therefore to make clear the effect of the membership functions and the model vehicle speed, and to scrutinize the basic properties of the response through the comparison with proportional action control, which is one of the typical feedback control system.

2. GROUND LEVELING BY USE OF FUZZY CONTROL

2.1 The rule of fuzzy control[7)]

In order to carry out fuzzy control test, the fuzzy control rules, so-called if~then rule, have to be decided by using the following relation.

If x=A then y=B

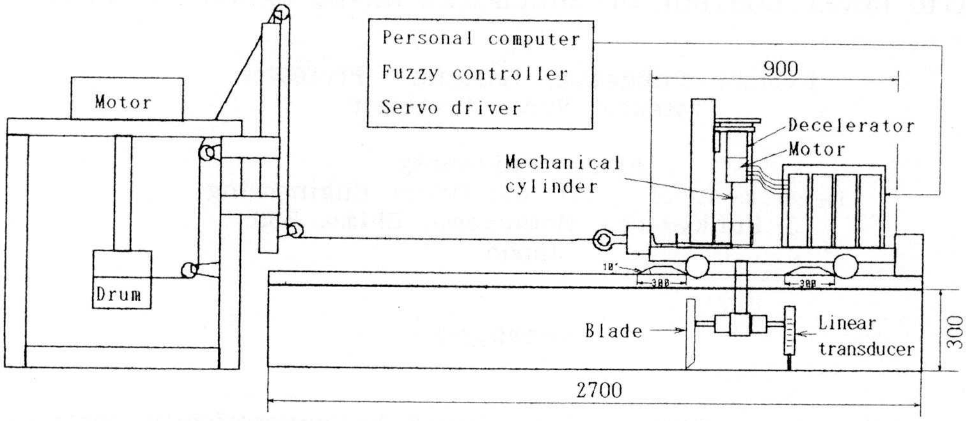

Fig.1 Schematic view of testing apparatus

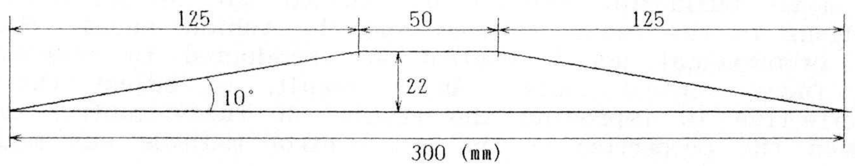

Fig.2 Dimensions of obstructions

Where x is the variable in the condition part of a membership function and y is the variable in the operation part. A and B are fuzzy linguistic information defined by such words as "very large" or "small" etc. Each fuzzy information in A and B is evaluated as a membership function and used in fuzzy reasoning.

2.2 Experimental apparatus

The outline of an experimental apparatus is shown in Fig.1. This apparatus consists of i)soil bin, ii)model bulldozing vehicle, iii) drawing apparatus, iv) blade and the controlling equipment. The dimensions of the soil bin are 270cm long, 60cm wide and 30cm high. The model bulldozing vehicle is drawn by winding a wire connected with the drum rotated by a motor. The drawing speed of the vehicle is ranged from 0.2 to 2.0cm/sec.

The vehicle equipped with two axles and four wheels which diameter is 7.5cm can travel freely on the rail set on the both upper end of the side wall of the soil bin. In the center of the vehicle, a mechanical cylinder, for which converts rotational movement to axial displacement, is equipped to make the blade up and down and this cylinder is connected to a servomotor with a rubber belt. The vehicle has also a fuzzy controller, power unit and servo driver used to control the servomotor. The maximum displacement speed of the mechanical cylinder is 17.0cm/min. A couple of linear transducers is mounted at the bottom of the mechanical cylinder in order to give input information to the fuzzy controller and to connect with data recorder respectively. A flat metal plate is horizontally put on the model ground as a reference surface. The dimensions of the plate are 150cm in length, 7.5cm in width and 1.5cm in thickness. Four obstructions shown in Fig.2 are set on the rail in front of the four wheels of the model vehicle, and the four wheels experience just the same displacement. In other words, the displacement of this vehicle occurs one dimensionally.

2.3 System constitution

The constitution of fuzzy control system is shown in Fig.3. At first some

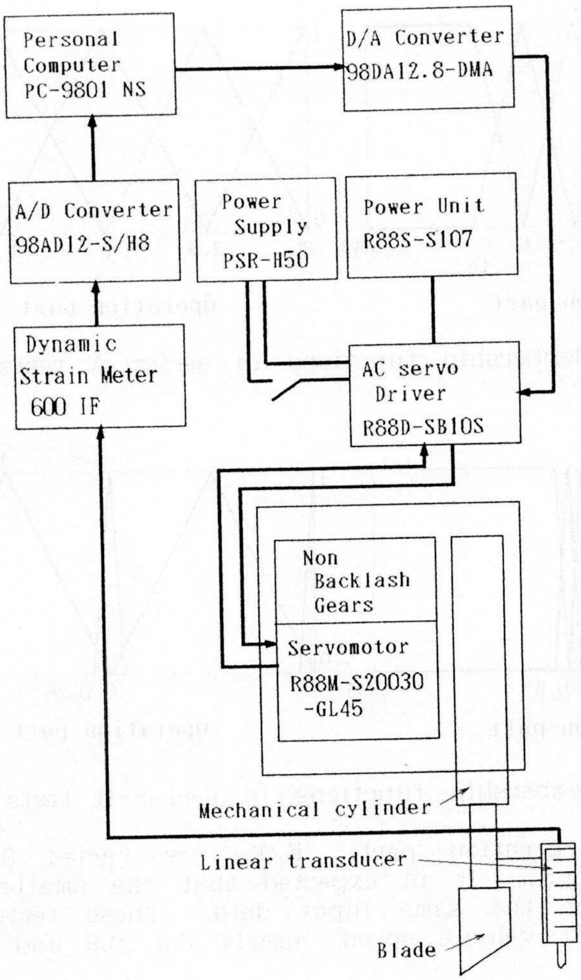

Fig.3 Fuzzy control system

fuzzy control conditions including membership functions etc. are transferred to fuzzy controller. The fuzzy controller is started to act based on the input data from linear transducer. The aim of power unit is to rectify alternating current and to supply direct current to servo driver. The servo driver is used for controlling voltage supplied to the servomotor. The voltage is proportional to the rate of the vertical displacement of blade in this system.

2.4 Decision of membership functions

In this section, the effect of membership functions is experimentally scrutinized. Generally speaking, the membership functions should be set to satisfy the speed of response and the relative stability. In considering these points, the following membership functions are set.

Series A) L/Lo, shown in Fig.4, in the membership functions of condition part is varied 0.05, 0.1, 0.2, 0.3, 0.4, 0.5 in order, while the membership functions of the operation part are kept constant. It is expected that smaller L/Lo gives a sensitive response against input data.

Series B) Since a good control result could be derived from the upper experiments corresponding to L/Lo=0.05 or 0.1, L/Lo in the membership functions of the condition part was kept constant in this series of tests (namely L/Lo=0.1). This series of tests are conducted to check the effect of

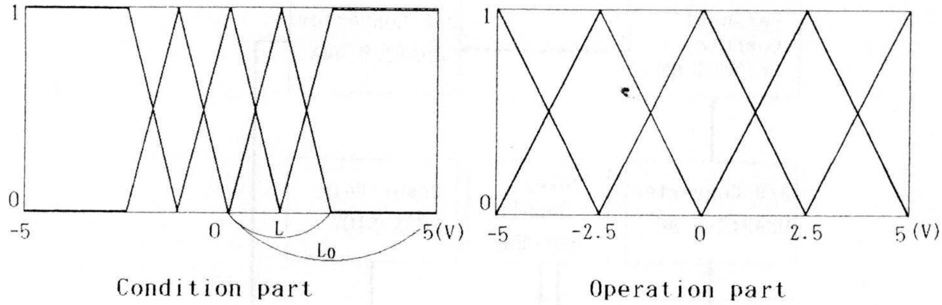

Fig.4 Membership functions in series A tests

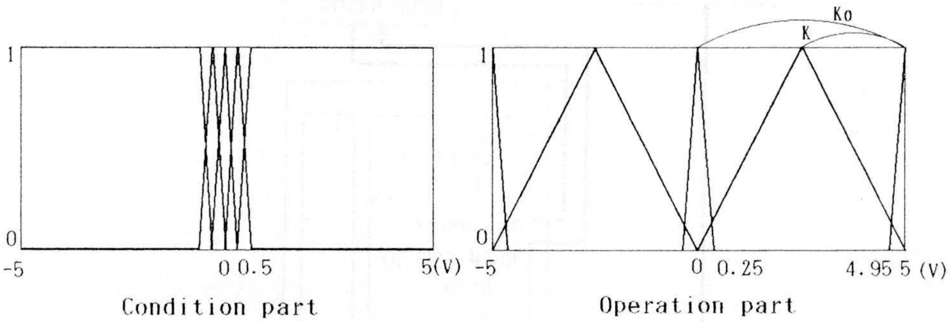

Fig.5 Membership functions in series B tests

membership functions of operation part. K/Ko is varied 0.05, 0.1, 0.2, 0.3, 0.4, 0.5 in order (see Fig.5). It is expected that the smaller values of K/Ko gives a bigger output for the same input data. These tests are carried out under three kinds of model vehicle speed, namely 0.2, 0.9 and 2.0cm/sec.

2.5 Change of vehicle speed

The effect of the model vehicle speed are investigated. Since a best combinations of the membership functions were decided from the upper experiments (namely K/Ko=L/Lo=0.05), these membership functions were used in this series of tests. Model vehicle speed is varied from 0.2 to 2.0cm/sec. The critical horizontal speed of the model vehicle corresponding to the maximum stroke speed of the mechanical cylinder is 1.61cm/sec judged by the slope angle of the obstruction. Since the maximum displacement speed of the blade is seemed to be important, the model vehicle speeds are selected every 0.1 cm/sec around this critical speed.

2.6 Data processing

The control results are monitorred by an ultrasonic linear transducer and recorded by use of a digital recorder. Data processing was carried out based on the about 100 data sampled at every 0.3cm of the horizontal vehicle movement. To evaluate the accuracy of controls, two kinds of indices are employed. One is the maximum value, Dvmax, of the vertical displacement of blade from the reference surface, Dv, and the other is the standard deviation, SD, of Dv. SD is defined by the next equation.

$$SD = \frac{1}{n} \sum_{i=1}^{n} Dv^2$$

Where, n is the number of samples.

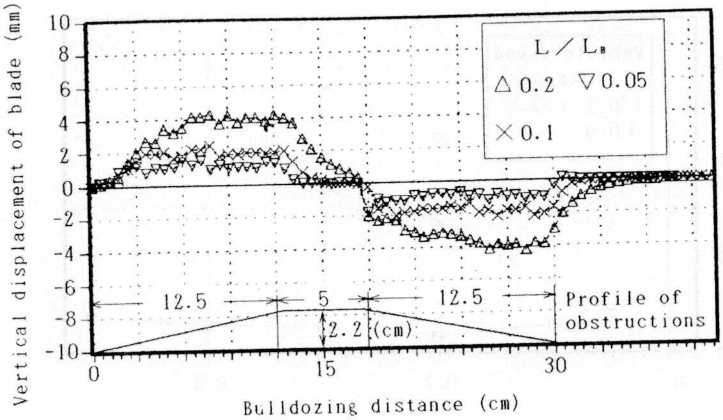

Fig.6 Typical example of the relationship between the vertical blade displacement from the reference surface and the bulldozing distance

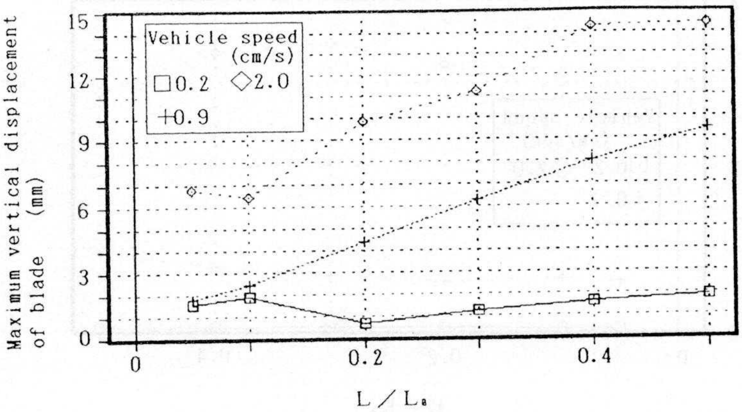

Fig.7 Effect of L/Lo on the maximum deviation of the vertical blade displacement from the reference surface

3. RESULTS OF FUZZY CONTROL TESTS AND CONSIDERATIONS

3.1 Effect of membership functions

The typical relationship between the vertical displacement of blade from the reference surface and the travelling distance of model vehicle is shown in Fig.6. In this figure, the vehicle speed is 0.9 cm/sec and L/Lo is varied from 0.05 to 0.2. The profile of obstructions is shown in Fig.6 again. When L/Lo is 0.05, the vertical displacement of the blade ranges at most from about 1.5 mm to about -1.5 mm and converges nearly zero just after passing the obstructions. While the results are not good in the case of L/Lo=0.2. It is judged by these results that the smaller L/Lo is better for the blade control. The same tendency as shown in Fig.6 was given in the other test cases.

The relationship between the maximum deviation of the vertical blade displacement from the reference surface and L/Lo is shown in Fig.7. The relationship between the standard deviation SD of the vertical displacement of blade and L/Lo is also shown in Fig.8. From these figures it can be concluded that the sensitivity for L/Lo of the blade response depends on the vehicle speed. Although the smaller L/Lo is advantageous for the blade control, a moderate L/Lo should be chosen because L/Lo smaller than about 0.1 is expected

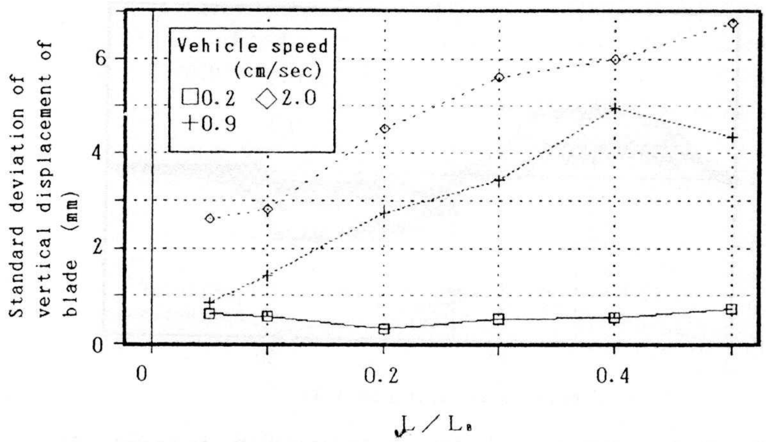

Fig.8 Effect of L/Lo on the standard deviation of the vertical blade displacement from the reference surface

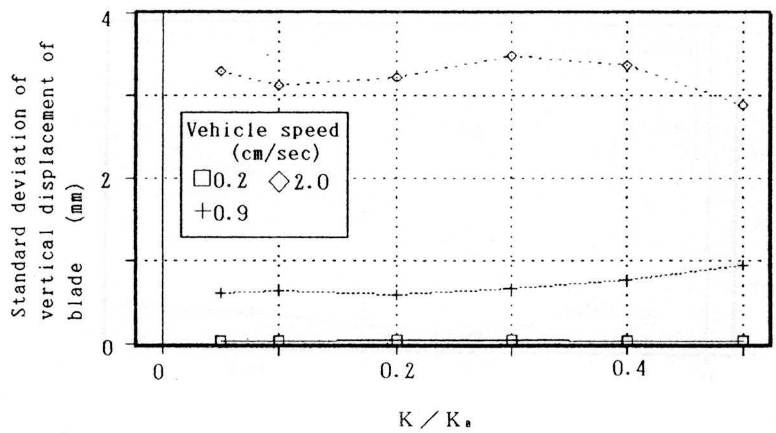

Fig.9 Effect of K/Ko on test results (L/Lo=0.1)

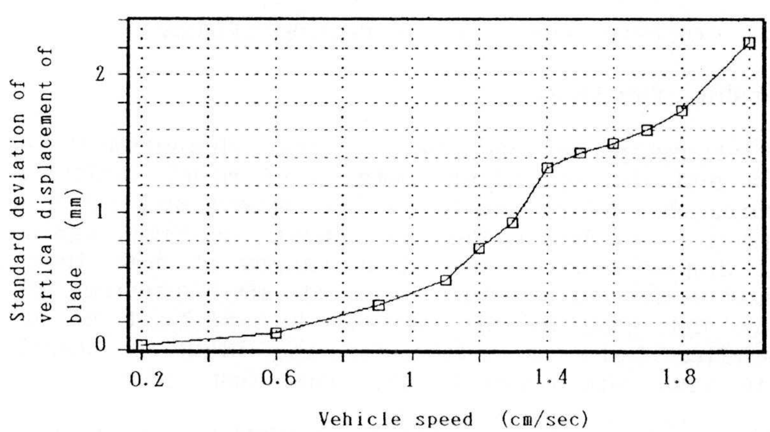

Fig.10 Effect of vehicle speed on test results (L/Lo=K/Ko=0.05)

to give almost the same result as in the case of L/Lo=0.05.

Next the effect of K/Ko in the operation part is investigated. In these tests, L/Lo is kept constant, that is 0.1. The effect of K/Ko on the standard deviation SD is shown in Fig.9. It is clear from this figure that K/Ko has little effect on the test results if compared with the effect of L/Lo.

3.2 Effect of vehicle speed

In this case L/Lo and K/Ko are equal to 0.05. The vehicle speed is varied from 0.2 to 2.0 cm/sec in order. The relationship between the standard deviation of the vertical blade displacement from the reference surface and the vehicle speed is shown in Fig.10. In this case, the tangential gradient of the curve becomes a little steeper where the vehicle speed exceeds about 1.1cm/sec. This speed is nearly equal to the 70% of the critical horizontal speed of the model vehicle (1.61cm/sec). Accordingly if the vehicle speed is under the 70 % of the critical horizontal speed of the vehicle, the test would give more stable result. Of course this boundary speed relies on the required accuracy of ground leveling.

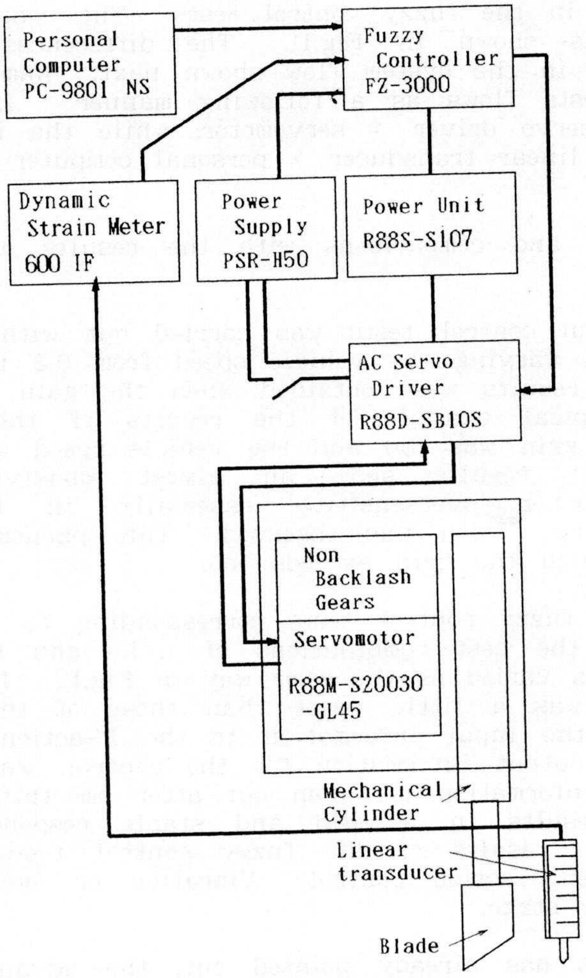

Fig.11 Proportional action control system

4. COMPARISON WITH THE RESULTS OF PROPORTIONAL ACTION CONTROL

4.1 Proportional action control[8)]

To compare with the results of the fuzzy control tests, a series of proportional action (P-action) control tests was carried out under almost the same test conditions as in the fuzzy control tests. The P-action is one of the basic actions constituting the feedback control. The principle of the P-action control is expressed by the next equations.

$$u = k_p \cdot e$$
$$e = r - b$$

where, u : control input, k_p : gain, e : deviation, r : reference input, b : primary feedback. If the gain k_p becomes larger and approaches infinity, the proportional band becomes nearly equal to zero and then the actions fully opened or fully closed are repeatedly conducted depending on the deviation. In this situation the P-action control is almost equal to the on-off control.

4.2 Experiments based on P-action control

Every experimental apparatus except the system for the P-action control is the same as those used in the fuzzy control tests. The constitution of the P-action control system is shown in Fig.11. The differences between the two control systems come out in the system flow shown next. Namely the information in the fuzzy control tests flows as a following manner : linear transducer > fuzzy controller > AC servo driver > servomotor, while the information in the P-action control flows : linear transducer > personal computer > AC servo driver > servomotor .

4.3 Experimental results and comparisons with the results of fuzzy control tests

A series of P-action control tests was carried out with varying the gain from 10 to 200 and with varying the vehicle speed from 0.2 to 2.0cm/sec. As a result, the best control results were obtained when the gain ranged from 75 to 125. Fig.12 is the typical example of the results of the P-action control tests. In this case the gain was 100 and the vehicle speed was varied 0.2, 0.6, 0.9cm/sec. Although the results show an almost satisfying accuracy, the response was often rather oversensitive especially in the uphill stage. Sometimes typical vibrating motion was observed. This phenomena is much more prominent in the test which the gain exceeds 150.

The results of the fuzzy control tests corresponding to Fig.12 is shown in Fig.13. In these tests, the best combinations of L/Lo and K/Ko were selected and the vehicle speed was varied as the same way in Fig.12. It can be seen that the speed of response was a little worse than those of the P-action control tests. This is because the input information to the P-action control system is directly changed to the output information for the control, while in the case of fuzzy control an input information is taken out after smoothing in a diffuzification process. This results in a mild and stable response. Therefore the relative stability of the results of the fuzzy control tests is seemed to be more satisfying than the P-action control. Vibration or over reaction is also not so remarkable in any stage.

As many researchers has already pointed out, the advantage of the fuzzy control is respected to become more outstanding in complicated systems in which a mathematical formulation is difficult. In this sense the experimental case in this study is not so suitable for showing the advantage of fuzzy control. But real ground leveling problems maybe require more complicated control conditions

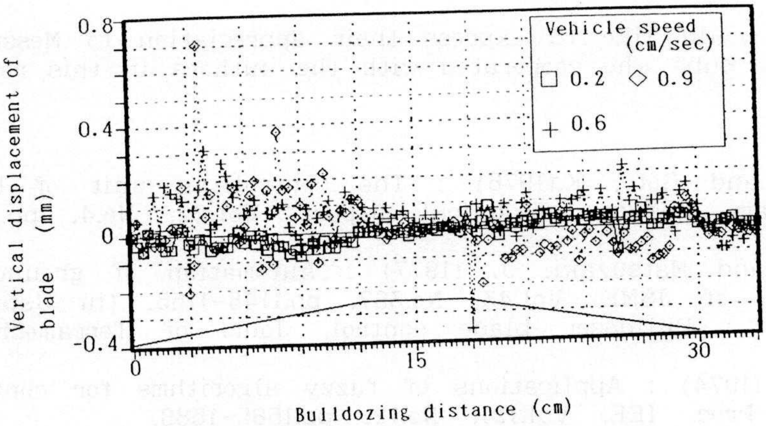

Fig.12 Result of P-action control tests (k_p=100)

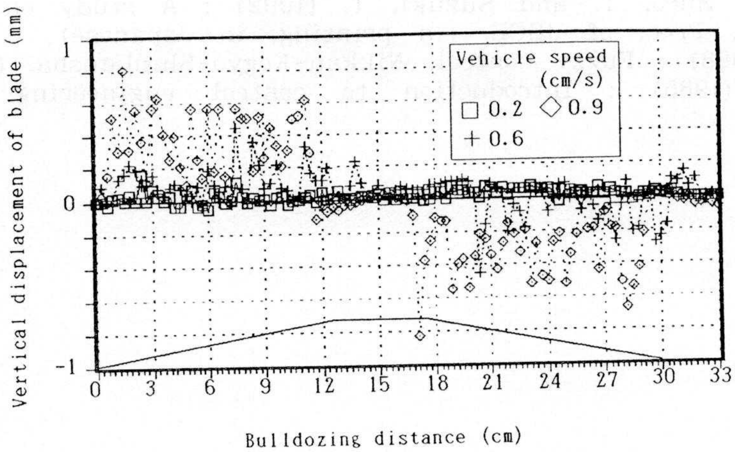

Fig.13 Result of fuzzy control tests (L/Lo=K/Ko=0.05)

including not only the deviation from the reference surface but the magnitude and the direction of the deviation increment since the ground conditions are varied easily and a hydraulic cylinder is usually used to control blades. These real situations will probably result in proving the advantage of fuzzy control.

5. CONCLUSIONS

Main conclusions obtained from this research are as follows.

1) L/Lo in the membership functions of condition part had much effect on the controlled results and the smaller L/Lo gave better accuracy of ground leveling.

2) Compared with L/Lo, K/Ko in the membership functions of operation part had not so much effect.

3) In the fuzzy control tests the effect of model vehicle speed was quantitatively evaluated.

4) Although the proportional action control tests give a little better accuracy than the fuzzy control tests, vibration or over reaction in the responses were sometimes prominent compared with fuzzy control.

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