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Development of three dimensional positioning automatic control asphalt paver

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ABSTRACT

This is a system that performs travel course control (automatic steering) of construction machines and three dimensional positioning control of working equipment simultaneously and with high accuracy, according to the design plan of the road.

This system consists of two blocks - a fixed station and a movable station (construction machine). The fixed station measures the three dimensional position of the target set in the movable station (construction machine) in real time using the automatic tracking total station linked to the computer, and compares the pre-set data. The movable station receives the comparison data, predicts the motion, and decides the control quantities for course control and posture control.

This system does not need the setting of a reference line for control. Therefore, the measuring process for work preparations and measurements during the work (checking the height, thickness, and other dimensions) can be eliminated. Since the measuring processes have been eliminated, human errors and mistakes are eliminated, resulting in the realisation of high accuracy.

The development of the asphalt paver has been carried out as a part of the overall technological development project "Development of New Working Technology in Construction Industries" of the Ministry of Construction.

1. INTRODUCTION

Automation of road paving work has progressed to some extent, but considerable labour and man-hours are necessary for work such as measurement work, preparations, and work controls. Since the status of work cannot be rationally extracted during the work, the accuracy and efficiency of the work and the large dependence on the skill of experienced workers are necessary factors at present.

Particularly, the basic concept is to work exactly according to the design plan. Preparatory processes, inspections and measurements during work (checking the height, the thickness and other dimensions) require a large amount of labour and man hours. To work exactly according to the design plan by conventional work, a wire rope has to be set up according to the design, after carrying out prior measurements. This wire rope is taken as the reference line, this reference line is followed, and simple profile control is performed. In this way, for conventional control of dimensions (height, thickness, breadth), some sort of reference line is necessary at the work site in addition to work preparatory processes such as measurement work, work for installing the measuring desk, and work for installing the wire rope. There is a large probability of human errors and mistakes in these processes. To minimise mistakes or errors, careful, meticulous work and checks are required, necessitating considerable time.

The "three dimensional positioning control asphalt paver" was developed to resolve problems such as these, and to realise a system that eliminates the preparatory processes, attain high efficiency and high precision in work.

2. SYSTEM CONFIGURATION

The system Configuration is shown in Fig. 1.

2.1 Fixed station

The fixed station consists of the computer at the centre, linked to the automatic tracking total station, the communications modem, display, magnetic disk, and printer. The fixed station operates according to the design plan, and performs measurements, calculations, and operations of the three dimensional position of the target installed in the movable station.

The automatic tracking total station tracks the target automatically using the laser scanner and drive motor connected to it, and measures the three dimensional position of the target in real time.

In the conventional total station, it is very difficult for a human being to continuously monitor the target when it is in motion or when the total station itself is in motion. Automatic measurement is possible using the automatic tracking total station even in this sort of condition.

2.2 Movable station

The movable station, with the computer at the centre, consists of the communications modem, display, silicone disk, control unit, and auxiliary sensors. The movable station receives the three dimensional position data of the target from the fixed station through the communications modem, and calculates the control quantities from the design values and error values.

Auxiliary sensors consist of several inclination sensors and displacement sensors used for detecting the posture of the vehicle or working equipment.
The control software is described later.

3. BASIC OPERATIONS OF THE SYSTEM

1. Calculate the design plan, and the planned working line using the computer on the side of the fixed station.
2. Install the fixed station at the installation position 1, between the temporary BM 1 and temporary BM2 points.
3. The fixed station calculates its own position by measuring temporary BMl and temporary BM2.
4. The fixed station automatically tracks and measures the three dimensional position of the target set in the working equipment of the asphalt paver.
5. The fixed station compares the design plan and the actual work surface, and calculates the error.
6. The fixed station transmits the three dimensional position data and the error quantities of the working equipment to the movable station.
7. The movable station measures the posture and speed of the vehicle and the working equipment, Using the various sensors installed in the asphalt paver.
8. The movable station predicts the motions in the vertical direction and the direction of travel, and calculates the control quantities.
9. The posture and steering of the working equipment are controlled by using the calculated control quantities.
10. If the constant distance (about 150 m) between the fixed station and the movable station is exceeded. the fixed station is moved from the installation position 1 to the installation position 2.

4. CONTROL PRINCIPLES

The control principles of this system are described below.

4.1 Basic design software

This is the sort ware for the fixed station having functions for calculating the design line for the road, and Control functions for measured position data.

The design line calculation software inputs the design data of the road in the computer, processes the data, and generates reference data for the work, prior to the start of work. The design data that is input includes various types of curves such as straight lines, simple curves, and easement curves (clothoid curves). only data of the co-ordinates of the start and end points, radius in case of a curve, road width, conditions for increased width, longitudinal and transverse slopes, are needed for the calculations. All the intermediate points are calculated by the computer using a 3O cm mesh and a three dimensional curved table is generated using the two dimensional mesh representing the road surface. These can be observed on the screen, and the control target position data can be referred to during the actual work.

4.2 Machine control software

4.2.1 Three dimensional posture control of working equipment

Conventionally, the control of working equipment made use of a reference line using a wire rope, and simple control was performed following the reference line. In this system, however, installation of a reference line on site is not necessary.
Inclination sensors are installed in the longitudinal and transverse directions on the working equipment. From the three dimensional measured data and longitudinal / transverse slope angles of the target mounted on the working equipment, the posture of the working equipment is calculated. Using the design plan data, the working equipment can be controlled to obtain the optimum posture.

Explanations are given below using a cross-section of the working equipment as an example. The Working equipment has a specific work stability angle depend on paved material. From the longitudinal slope obtained from the working stability angle and design plan data, the assumed value of stability angle theta10, is calculated. The key point in control is to bring the current working angle theta10 close to the assumed stability angle theta10, which is the target. If the error in the vertical direction is not eliminated even if the assumed stability angle of the target is controlled, then the setting of the stability angle is automatically adjusted by means of the learning function.

4.2.2 Course control (steering control)

For course control of this system, the co-ordinates of the centre of the vehicle shaft are calculated from the continuous shift measurement data of the target, and the course is controlled so the found, and this value is taken as the change in steering angle. A displacement sensor fitted in the hydraulic steeling cylinder, always measures the steering angle. Based on the co-ordinates x and y of the centre of the vehicle shaft that have been calculated, the current position on the planned line and the plane surface error calculation delta R (distance from the planned line) is obtained after referring to the design plan data. From the increase or decrease of the plane surface error., the proximity speed Vr is calculated. The R direction acceleration (Steering rotation quantity) command is obtained from the plane surface error delta R and the R direction corrected speed Vr, by referring to the phase plane. The steering angle during straight line travel and the steering angle corresponding to the radius of curvature of the design plan line are added, and the assumed stable steering angle theta r0 is calculated. The acceleration command value (steering angle) obtained by referring to the phase plane, is added to the stable steering angle, and taken as the steering angle for the next time. The difference in the steering angle for the next time and the measured steering angle is found, and this value is taken as the change in steering angle.

The course control system also has the learning function. If the error is not eliminated even if the steering angle is controlled in the assumed stable steering angle of the target, then the setting of the stable angle is automatically adjusted by the learning function.

4.2.3 phase plane control

This system has phase plane controls.

The Phase plane consists of the displacement quantity that is to be controlled and the two dimensional plane of motion speed. A fuzzy membership constant is arranged on this plane, and acceleration is set as the output. The operation of the control system varies according to the acceleration setting, therefore, an optimum pattern setting is necessary according to the properties of the item to be controlled.

The setting of fuzzy control rules and the status of correction of locus and actual displacement on the phase plane are according to Fig.4 to Fig.7. Ill the phase plane control Shown in Fig.4, the acceleration of "+++" is extremely large at the displacement position 1. From position 1 to position 2, the rise in speed is quick, and the control is such that the displacement is reduced within a short time. At position 2, the acceleration changes from "+" to "-" and the motion speed drops steeply, until the displacement at position 3 becomes zero. However, the motion speed will not become zero suddenly, therefore, the displacement will be in the opposite direction, as from position 3 to position 4. To correct this displacement in the opposite direction, the acceleration from position 4 to position 5 also becomes "-." A "+" acceleration is obtained in the reverse direction at position ·5, but at position 6, the displacement overshoots zero, and finally converges at Position 7.

Fig.5 allows the relation between time and displacement and indicates the motion. The phase plane control of Fig.4 shows speedy correction of displacement, but the correction is excessive, resulting in poor stability.

Fig.6 shows the phase plane controls used in this system. when the displacement is at position 1, the acceleration is at the boundary of "++" and "+". From position 1 to position 2, the rise in speed is comparatively high. From position 2 to position 3, the acceleration becomes "O" and the displacement reduces at a constant motion speed. At position 3, the acceleration becomes "" and the motion speed decreases. At position 4, the acceleration becomes "O" and at position 4, both motion speed and displacement converge to "O."

Fig.7 expresses this motion by showing the relationship between time and displacement. The phase plane control of Fig.6 is an ideal pattern, where the correction is done speedily, without excessive correction.

5. RESULTS OF TEST WORK

Results of the test work carried out within the premises using the asphalt paver loaded in this system, are reported below.

Tests were carried out over a straight line course, as shown in the example of the screen display in Fig.8 and included simple curves. Fig.8 shows the results of the tests. The central horizontal line is the control target line.

Regarding course control, the plane error at start was small, and when the direction did not change significantly, the error converged to within +/-5 cm, indicating extremely satisfactory results.

For three dimensional positioning control of working equipment, a tendency for vibration was observed but its range of fluctuation was mostly within +/-1 cm, which can be used for road bed work and pavement of intermediate layers.

Examples of screen displays during control are shown in fig.9. on the right side of the figure, the current position of the asphalt paver is plotted together with the planned work line in the form of red dots. On the left side, the steering deviation and the deviation in inclination of the work equipment are displayed in the metric system. By the side of this, the plane error of the centre. of the rear wheel (distance from the Planned line) and height error of the left / right working equipment are displayed by kinked line graphs.

6. CONCLUSIONS

Examining the trial constructions it is verified that there is no problem of immediate actual implementation of this system in terms of accuracy. This system is very effective with regard to shortening the road paving periods, improving the accuracy of operation, and reducing labour requirements.

The features and results of this system are given below.

1. Measurement work and work setup can be simplified by directly taking the design data of the road as the reference data for work.
Fig.lO allows a comparison of the preparatory work processes of the conventional control system and the present system.
2. Perform travel course controls of the asphalt paver unit without installing measurement desk, sensors, ropes, and other reference lines
3. The postures of all the work equipment are controlled in three dimensions with high accuracy according to the design plan.
4. Work controls and dimensional controls will be integrated in future, enabling a total system to be used.
5. This system can be used for automation of all other construction machines, obtaining high accuracy, and for reducing the high level of skill that was required conventionally.

The prototype of this system is presently being checked and tested. The principles of the system have been verified by tests but problems such as accuracy and technology for mass production need to be resolved, therefore, some more time is necessary to attain practical realisation. In future, top priority will be given to extracting and resolving these problems to progress toward practical realisation of this system.

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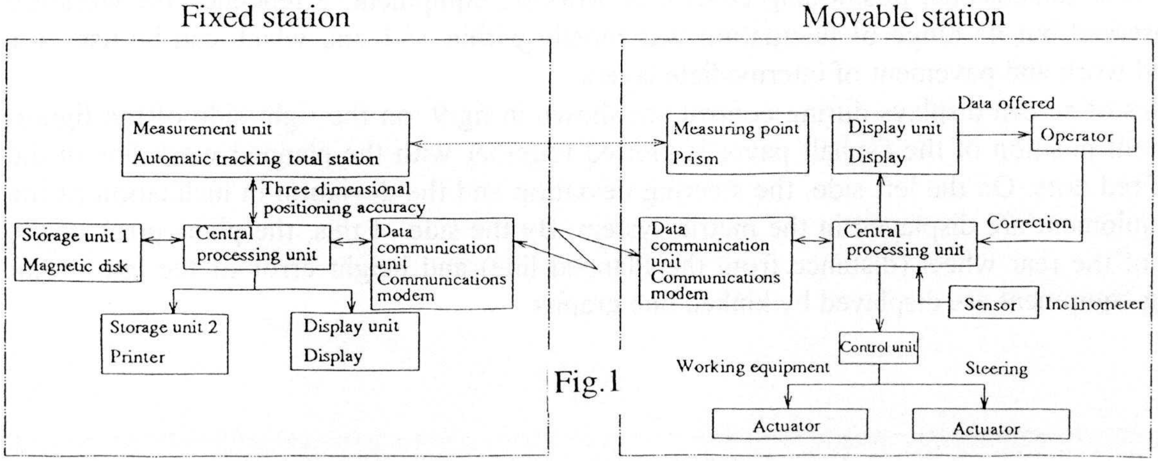

Fig.1

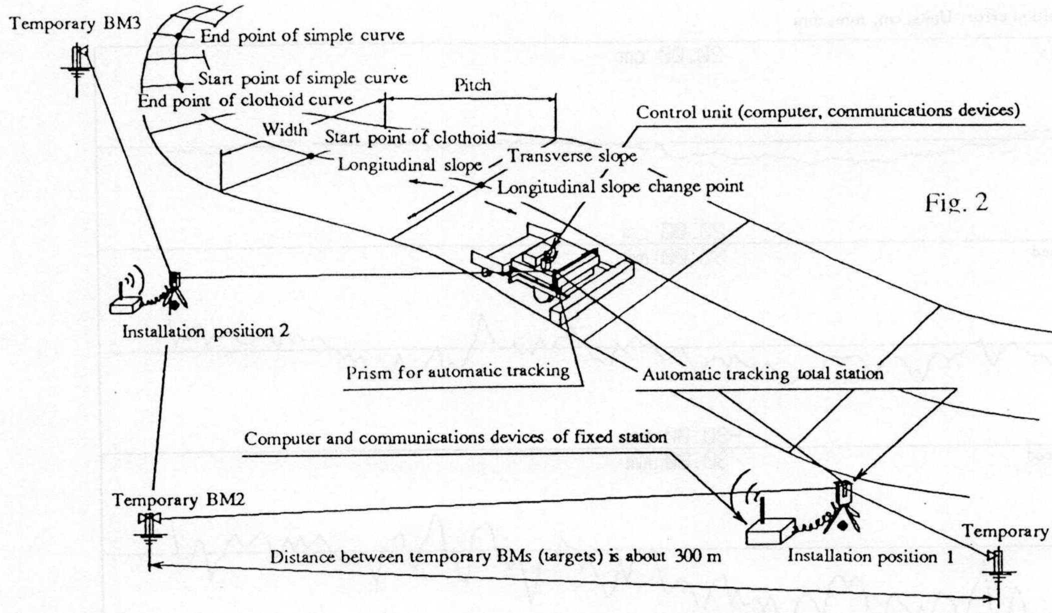

Fig. 2

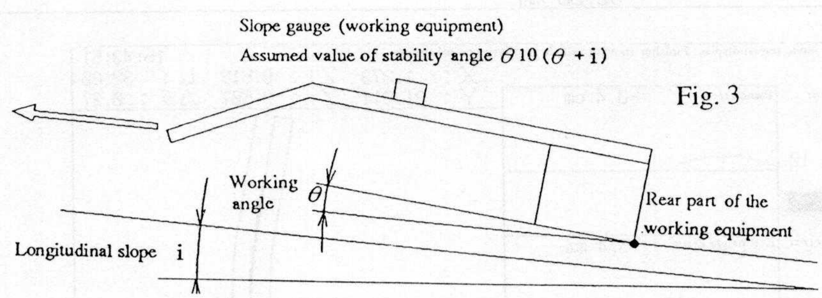

Fig. 3

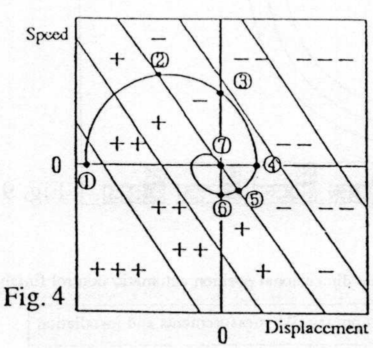

Fig. 4

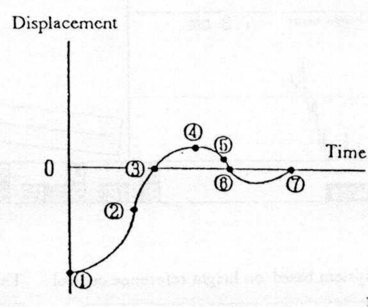

Fig. 5

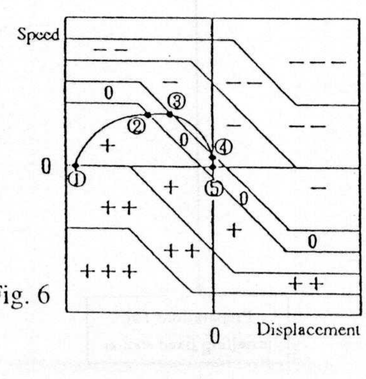

Fig. 6

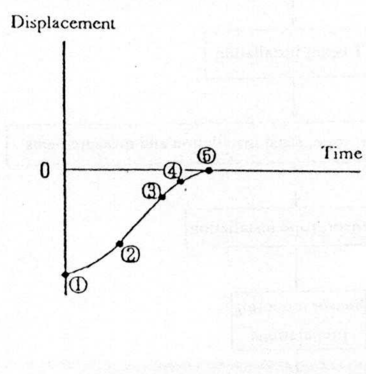

Fig. 7

±10 mm accuracy on asphalt

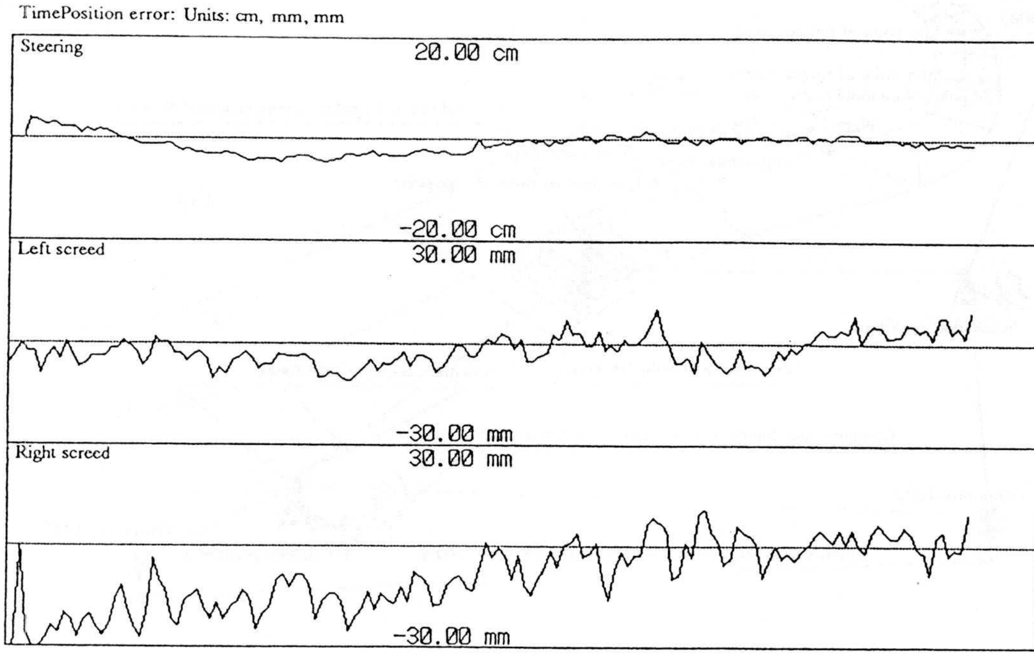

Fig. 8

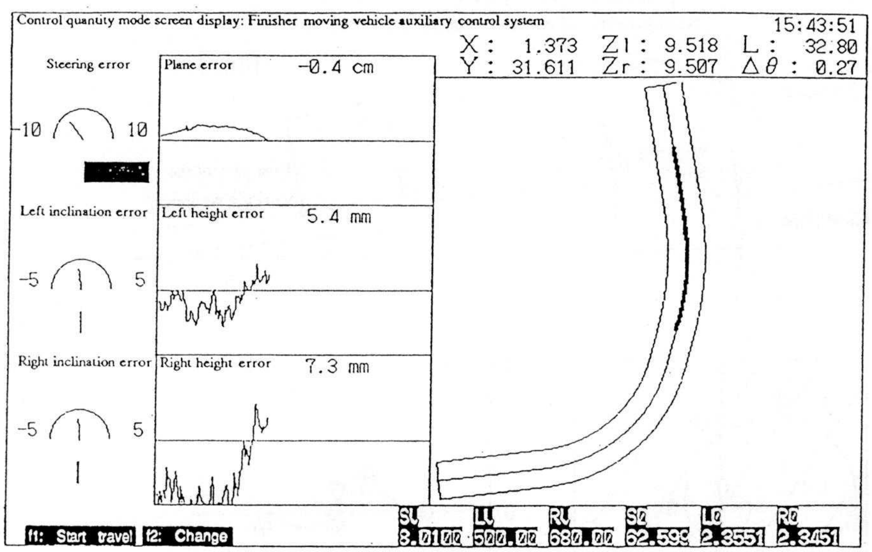

Fig. 9