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Evaluation and Modification on the New Concept Plow

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Abstract

Further evaluation and modification were done on the new concept plow (frontal plow), a plow which inverts the soil furrow without lateral displacement. First, kinematics of soil cutting section was analyzed and an experiment was conducted to report draft and power requirement. Second, function of main moldboards was examined and modification was made. As a result of the modification, force applied to the moldboard was reduced, but the furrow inversion became less stable.

Key Word: Inversion at the same position, Oscillatory tillage, Moldboard

1. Introduction

The new concept plow was investigated to invert the soil furrows at the same position without lateral movement. Since 1983, elements and structure of the plow had been designed, and a prototype was constructed for paddy fields. Its function was almost successfully achieved, and the performance was reported (Kawamura et al. 1986, 1988).

Figure 1 shows a scheme of the unit prototype. As it is shown in the figure, two gangs make one unit, up to three of which the prototype can mount. First, the furrow is cut vertically with the disk coulters. Second, it is cut horizontally with the share attached to the PTO-driven oscillating shank. The moldboard A, which is fixed to the share will accomplish initial inversion of the furrow. Third, when the furrow comes out behind the plow frame, it is trapped by the main moldboards B and C. Referring to the top view, the moldboard B pushes lower part of the furrow to the left, and the moldboard C pushes the upper part to the right. Finally, the furrow will be inverted to about 135 degrees, where most stubble and residue are buried.

2. Kinematics and Dynamics of Oscillating Parts

This chapter deals with the oscillating parts; shank, share, and moldboard A. First, kinematics of the parts was analyzed from geometric configuration. Then an experiment was conducted to measure the crank shaft torque and the draft at the parts as a whole (noted simply 'the draft' in this chapter). The draft within a oscillation cycle and effect of operational condition are discussed.

2.1 *Kinematics*

Figure 2 shows schematic diagram of the oscillation. The mechanism is formed out of links and a crank. It is designed so that there are two motions of oscillation within one revolution of the crank shaft. Shank angle θ_6 is defined as a function of the crank angle θ_2, and it is close to harmonic curve as is shown in figure 3. Amplitude at the share tip can be calculated by multiplying amplitude of the θ_6 by R_7, which is 58mm. Share tip velocity can be expressed as equation (1) and (2), from which an example of the locus is shown in figure 4.

$$V_x' = V_g + \dot{\theta}_6 \cdot R_7 \cdot \cos\alpha \quad (1)$$

$$V_z = \dot{\theta}_6 \cdot R_7 \cdot \sin\alpha \quad (2)$$

where,

$\alpha := 5.83 - \theta_6$ rad

V_g: Average ground speed = Operational speed

Certain variables are going to be expressed in reference to the crank angle θ_2 in this chapter, since $\dot{\theta}_2$ can be regarded to be constant.

2.2 *Method of experiment*

One unit of the plow was mounted in the middle of the frame, and was driven by a 18kW 4-wheel drive tractor. Experimental conditions are shown in table 1.

Strain gauges were attached to the crank shaft and to the shank, and the torque and the draft were measured respectively. Data were sampled every 5ms, and when mean values were required, they were treated with moving average within a period of the θ_2.

Two-axis acceleration transducer was attached to the shank to check real velocity at the share tip. The velocity was calculated by integrating the signal from the transducer, under the assumption that the plow frame did not have pitching during the operation, and that the shank had the motion exactly as calculated in reference to the frame.

2.3 *Results and discussion*

2.3.1 Draft and share velocity within a cycle

The draft within a period of crank angle θ_2 can be significant function of the share velocity, as it is shown in figure 5(a) as an example. Negative draft was observed in the neighborhood of points where the share velocity becomes minimum. It is explained from the locus of the share tip (figure 4) that the share pushed untilled surface when it moved backward, which would emerge driving force to move the plow frame forward. On the contrary, figure 5(b) shows no negative draft, since the locus does not have overlap.

The observed share tip velocity deviated from the theoretical one, especially at the points where the latter value becomes exremum. It is assumed that the plow frame vibrated horizontally to reduce the peak of the velocity: the frame was pushed forward when the share was in backward motion, and was pulled backward when the share was in action of soil cutting. This assumption can be supported by the fact that the share amplitude is small enough (58mm), and that certain vibration was found at the operator's seat.

2.3.2 Effect of operational condition

Operational speed and oscillation mode have effect on the draft. Figure 6 shows that the draft gradually increases as the operational speed increases, and the oscillation has effect on reducing the draft. However, the effect of the operational speed is not as clear as in the figure 5. This would be attributed to the condition that range of the operational speed was not wide enough.

Total power requirement at the oscillating parts was calculated from the draft and the crank shaft torque, and is shown in figure 7. When the shank was oscillated, more power was necessary in return for draft reduction. Particularly, the faster oscillation has higher power requirement (figure 7) compared to its effect on the draft reduction (figure 6).

3. Measurement and modification on main moldboards

This chapter discusses the function of the main moldboards B and C to clarify what kind of shape is essential and what kind of forces is applied to invert the furrow. First, shapes of the moldboards were written, and small modification was made on the moldboard B. Then, an experiment was done to measure the force applied to the moldboard C. Effect of the modification, depth, and operational speed is discussed.

3.1 *Expression and modification of the moldboard surfaces*

Surfaces of the moldboard B and C were sampled with height gauge, and their cross sections are written in figure 8(a) together with description of furrow inversion. It is recognized that they have helicoid surfaces. The figure shows that the furrow passes relatively open space at the beginning, and becomes restricted and inverted by the moldboards toward the end of the operation. Since bottom and top of the furrow contact with the moldboards at the end, it is expected that the forces applied to the moldboards would increase as the depth increases. The maximum limit of the depth would be found around 160mm. On the contrary, if the depth is too small, the furrow can not be trapped by the moldboards, which will result in complete inversion.

To cope with the restraint of the depth, small modification was made. The authors designed a smaller moldboard B whose shape is expressed in figure 8(b). It was designed so that the modified moldboard B would only leave the function to push the lower part of the furrow to the left.

3.2 *Method of experiment*

As it is shown in the figure 1, the moldboard C was attached to a L-6-component force transducer (Hata. 1979), from which both three components and point of application were calculated. The draft of the moldboard C coincides to the x component of the applied force.

An experiment was conducted in a rice paddy field after the harvest, in which soil furrows were sticky enough not to collapse during the operation. One unit was attached to the frame, and was driven by a 18kW 4-wheel drive tractor. Table 2 represents field condition and experimental design.

3.3 *Results and discussion*

Examples of force applied to the moldboard C are shown in figure 9. The moldboard is expressed in the third angle projection, and the stripes are written every 50mm along the x axis, so that the side view can recall three dimensional shape to the readers. Force vectors are written every 0.5 seconds during the stable operation, and the circles are substitution for arrows.

With the original moldboard B attached (figure 9(a)), the force vectors are found around the upper part of the moldboard C. This fact certifies the function of the moldboard C: push upper part of the furrow to the right (Chapter 1).

On the other hand, with the modified moldboard B attached, points of application distribute around the surface, although the force itself becomes smaller. The reason is attributed to stability of the furrow inversion: there was certain period when the furrow could not be inverted completely during the operation. This is due to the configuration of the moldboards, which allows less constraint to the soil furrow.

Figure 10 shows effect of the modification in terms of the draft at the moldboard C. The draft was reduced down to about the half when the modified moldboard B was attached. The figure also shows that the draft increased as the depth increased when the original moldboard B was attached.

However, effect of the speed is not clearly displayed for both types of the moldboard B. This will be partly attributed to the fact that the moldboard is only concerned with inversion without any action neither to throw away nor to cut the soil furrow. It also has to be taken into consideration that the speed range was not wide enough to see its effect.

4. Conclusion

The oscillation mechanism gives two quasi-harmonic motions within one revolution of the crank shaft, as long as the crank angular velocity stays constant.

Draft at the oscillating parts related to the share velocity within a cycle. Negative draft was observed when the share moved backward, and the observed share velocity deviated from the calculated value.

Oscillation reduced the draft in return for increase in total power requirement at the oscillating parts. Proper mode of oscillation should be chosen to balance the draft reduction and the power requirement.

The main moldboards inverted soil furrow by regulating its motion during the operation. Depth was found to be potential obstacle for operation, and the moldboard B was modified

When the original moldboard B was used, inversion was stable, and the force applied to the moldboard C increased as the depth increased. When the modified moldboard B was attached, the force was reduced, but inversion became less stable. The results imply need for further investigation of the moldboards.

References

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Table 1

Experimental condition (1)

Field condition	
Soil type	sandy loam
Moisture content	15-17 %d.b.
Bulk density	1.3-1.5 g/cm^3
Soil hardness (cone penetrometer)	120-180 MPa
Experimental design	
Oscillation	$\dot{\theta}_2$=0, 27.6, 33.3 rad/s
Operational speed	0.06-1.12 m/s
Depth	80 mm

Table 2

Experimental condition (2)

Field condition	
Soil type	clay loam
Moisture content	42-50 %d.b.
Bulk density	1.3-1.5 g/cm^3
Soil hardness (cone penetrometer)	11-27 MPa
Experimental design	
Oscillation	$\dot{\theta}_2$ = 0, 27.6 rad/s
Operational speed	0.2-0.8 m/s
Depth	70-140 mm

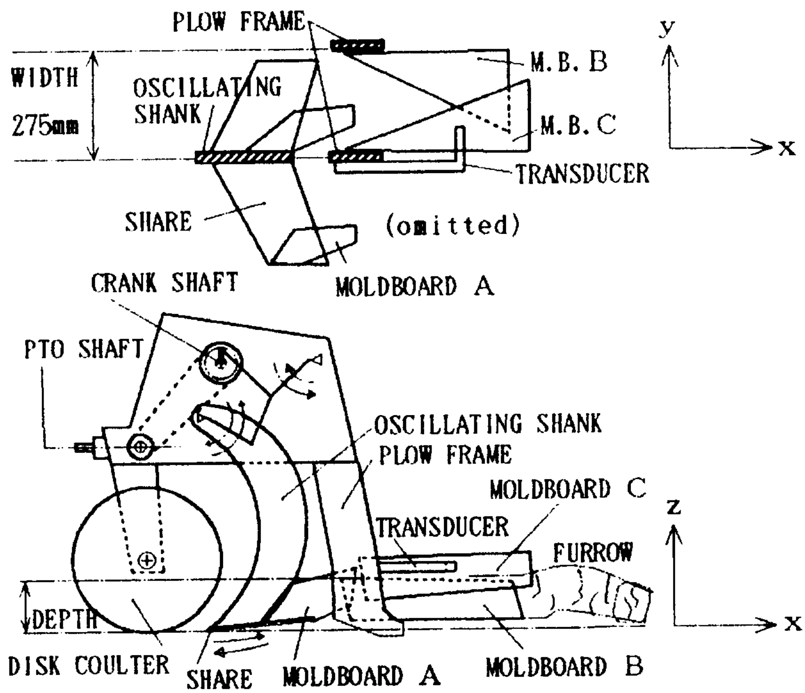
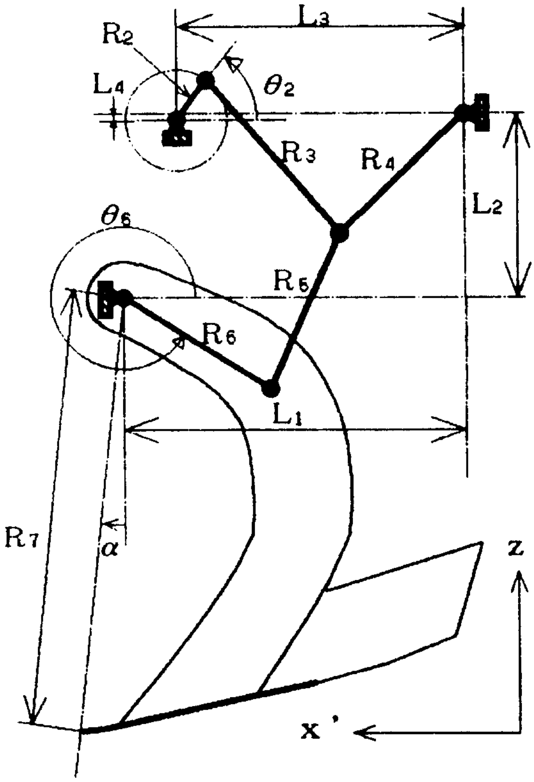


Fig. 1. Scheme of plow unit



	[mm]
L_1	295.3
L_2	159.0
L_3	248.4
L_4	4.0
R_2	45.2
R_3	200.0
R_4	150.0
R_5	150.0
R_6	150.0
R_7	600.0

Fig.2. Diagram of oscillation

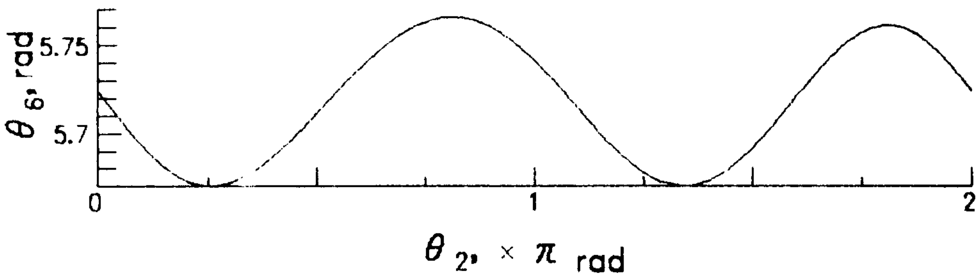


Fig.3. Change of shank angle θ_6

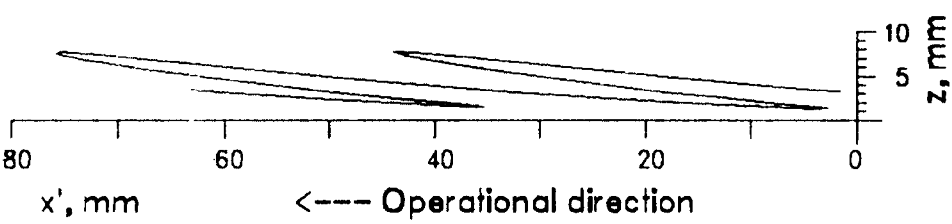


Fig.4. Locus of share tip
(V_g=0.26 m/s, $\dot{\theta}_2$=27.9 rad/s)

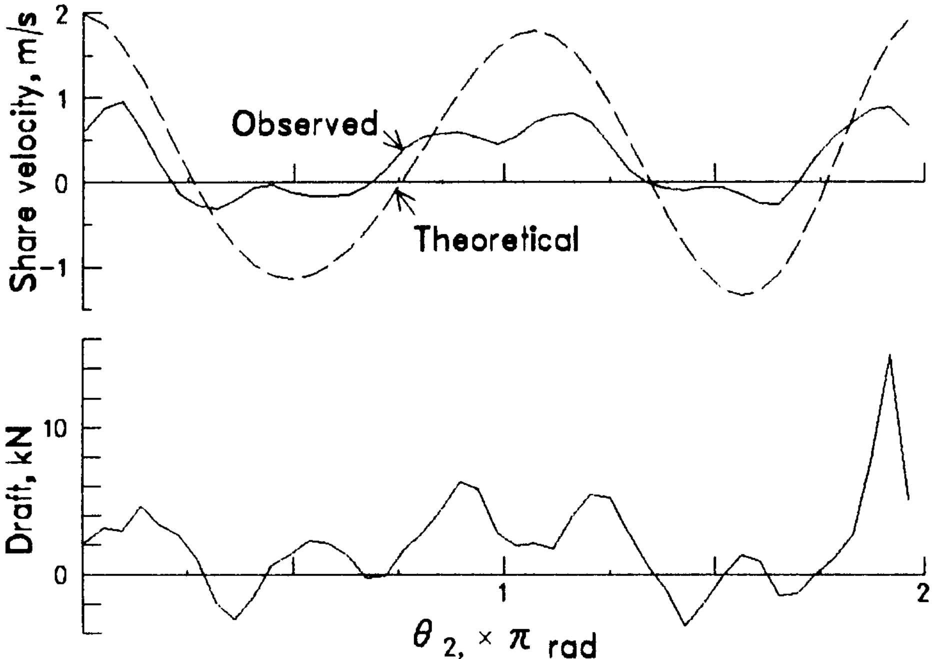


Fig.5(a). Comparison between share velocity and draft
(Vg=0.26 m/s, $\dot{\theta}_2$=27.9 rad/s, depth=75 mm)

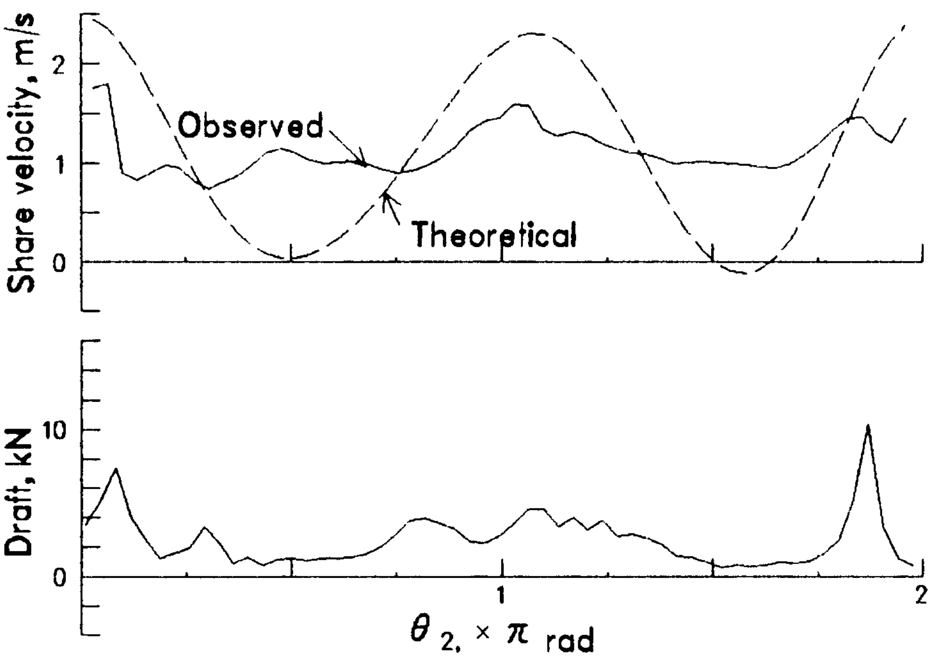


Fig.5(b). Comparison between share velocity and draft
(Vg=1.12 m/s, $\dot{\theta}_2$=24.2 rad/s, depth=80 mm)

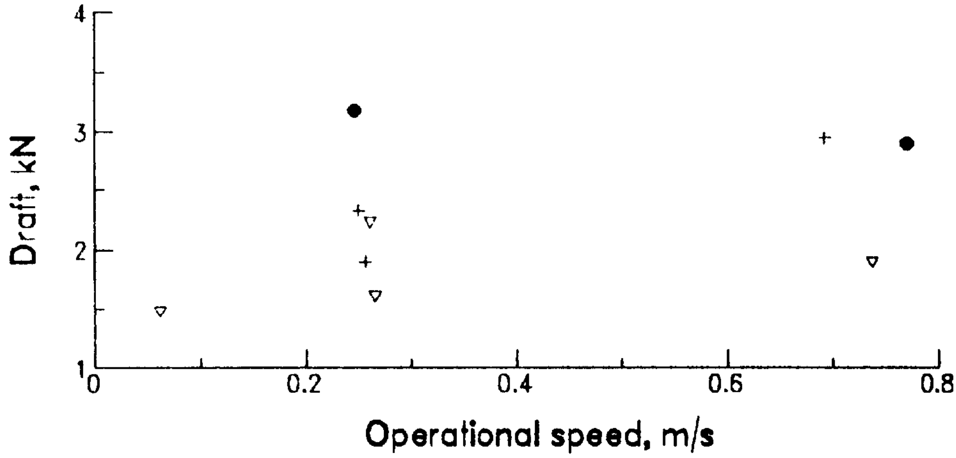


Fig.6. Effect of operational speed and oscillation mode on draft at oscillating parts

▽ : $\dot{\theta}_2$=27.6rad/s, depth avg.=81.9mm
+ : $\dot{\theta}_2$=33.3rad/s, depth avg.=84.5mm
● : Without oscillation, depth avg.=81.5mm

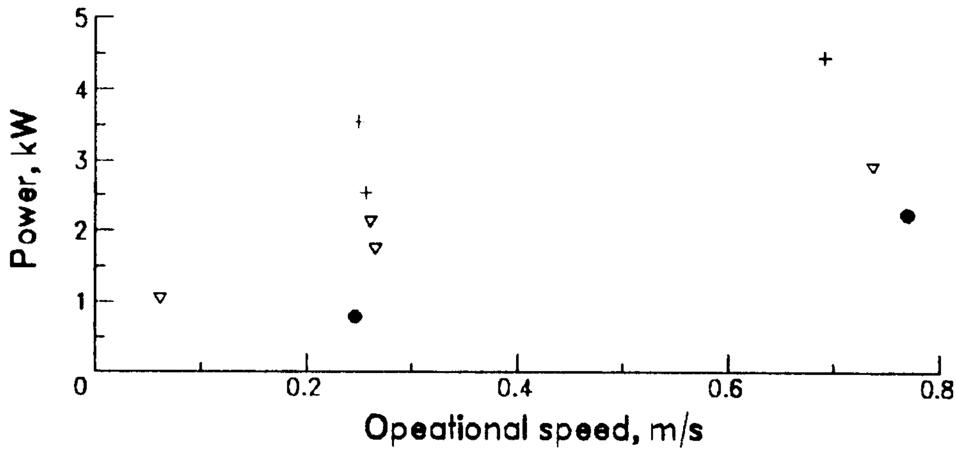


Fig.7. Effect of operational speed and oscillation mode on power requirement

▽ : $\dot{\theta}_2$=27.6rad/s, depth avg.=81.9mm
+ : $\dot{\theta}_2$=33.3rad/s, depth avg.=84.5mm
● : Without oscillation, depth avg.=81.5mm

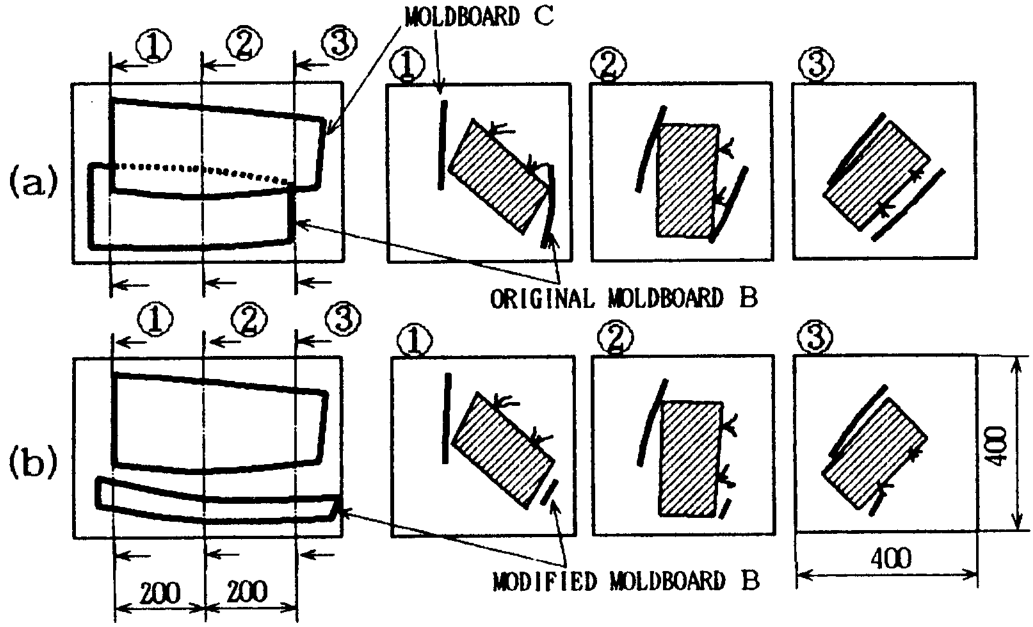


Fig.8. Cross sections of main moldboards and description of furrow inversion
(a) with original moldboard B
(b) with modified moldboard B

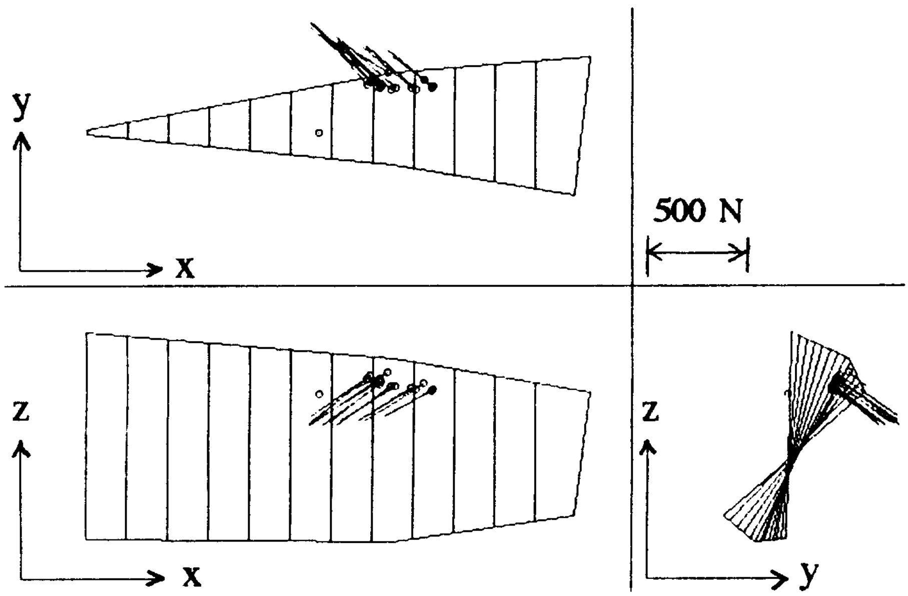


Fig.9 (a). Example of force applied to moldboard C
With original moldboard B,
Operational speed=0.51 m/s, depth=120 mm

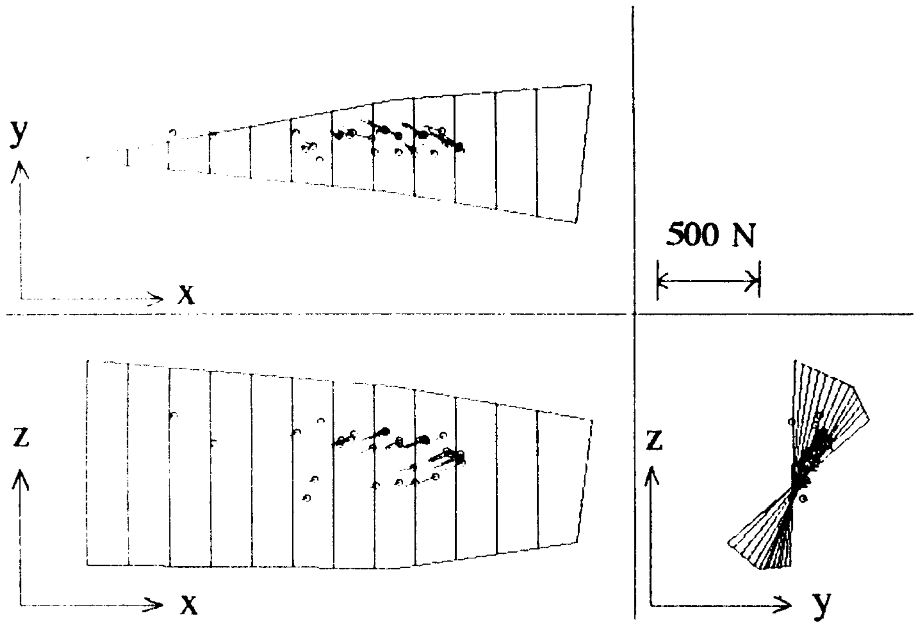


Fig.9.(b) Example of force applied to moldboard C
With modified moldboard B,
Operational speed=0.22 m/s, depth=110 mm

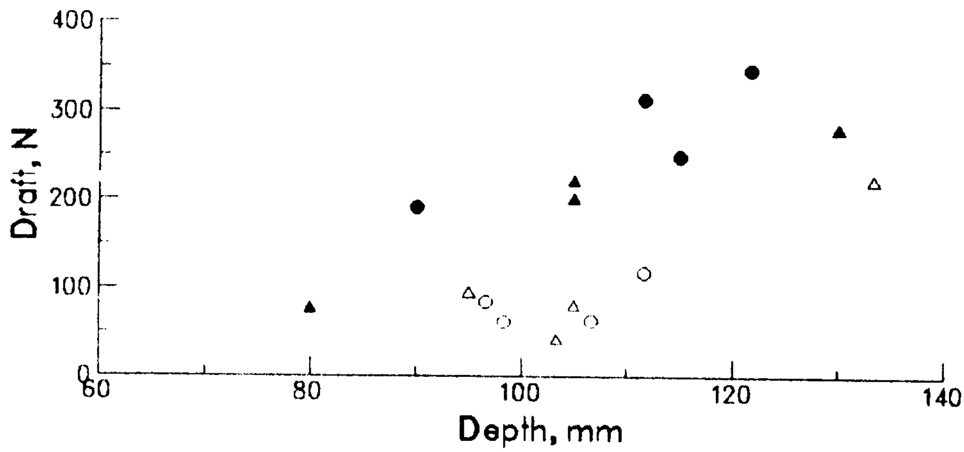


Fig. 10. Effect of modification and depth on draft at moldboard C
▲:With original m.b.B, speed avg.=0.26m/s
●:With original m.b.B, speed avg.=0.54m/s
△:With modified m.b.B, speed avg.=0.31m/s
○:With modified m.b.B, speed avg.=0.61m/s