OPERABILITY ASSESSMENT OF INDOOR DISMANTLEMENT ASSISTANCE MACHINE

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Abstract: Hydraulic crushers are available in dismantlement circumstance for example office buildings. Because the crushers weigh 35 to 50kg, adopting new accessory functions were highly expected for saving work/worker and improvements on safety. In this study, an indoor dismantlement assistance machine, which could be stably controlled by a single worker, was developed and operability assessment was done. For operability assessment, two conditions: easy-to-move on (ⅰ).one direction, (ⅱ). every direction, are compared to evaluate the priority of work efficiency. First, notation system to combine the machine's Mobility Ellipsoid and the worker's Manipulating Force Ellipsoid into one ellipsoid (i.e. Workability Ellipsoid) was suggested. The Workability Ellipsoid describes the machine-head mobility distribution, and the major axis direction: its length varies with its viscosity resistance and the working posture. By adopting this feature, the crane arm's viscosity resistance and the working posture were decided.

Keywords: Manipulability Ellipsoid, Jib-crane, Balancer, and Operability.

1. INTRODUCTION

Lately, an advance of work support machinery to the work site, such as robot, is performed positively for saving work/worker and improvement of safety. With an expansion of renewal businesses such as office buildings, introduction of the work support machinery is demanded in concrete wall dismantlement circumstance. The reason is because it works while two workers maintain the crusher from which weight is 35kg - 50kg both sides [1]. Because of unsteadiness in construction work sites, complete automation in the circumstance is difficult [2]. Therefore, the machine, which can work cooperatively with a worker, is needed in such environments. It is demanded that the machine can maintain a crusher and can move cooperatively with a worker. At first, in maintenance, a space of movement in the circumstance is limited so that the machine, which can move freely in a constant range, is suitable. Therefore the maintenance is realized by the work assistance machine, which has non-drive horizontal joints and a perpendicular joint carrying a mechanical balancer. Next proper operability to move with a worker in the space must be realized by a structure of the machine and a relation of the worker and the machine.

In the operability, there are many studies paid attention to human beings. For example, a study focused on a human posture for the machinery design [3]-[5], or a study paid attention to human characteristic at the time of the repetition movement and the posture maintenance [6]-[8]. Also the machinery side is analyzed. Yoshikawa [9] suggests a Manipulability Ellipsoid and Manipulating Force Ellipsoid about a manipulator characteristic for the easiness index to move itself and to put force in a space. Chiu [10] suggests the compatibility index deciding the posture that is most suitable for specific work. Manipulability, in the case, that loads is increased on the manipulator end point, besides various studies about a manipulator are reported [11]-[15]. On the other hand, in this circumstance a worker grasps the assistance machine directly then operates the non-drive arm of many joints. But there are not many studies that are examined the operability when a human being operates the machine directly more than two DOF.

Therefore, in this paper, an analysis technique how the ellipsoid expresses operability of the cooperation work based on an index about structure and posture of the assistance machine and posture of the worker is suggested. The analysis is applied to an operability evaluation of the developed machine and a worker, and it is aimed a machine design corresponding to the environment. Therefore, it is shown that a parameter of the most suitable ellipsoid shape is decided for straight-line movement through an operation experiment, and structure of the machine that is effective for the work.

2. BASIC MODEL OF THE ASSISTANCE MACHINE

In the dismantling field, a worker stands on a scaffold installed in both sides of a concrete wall like figure 1. And the worker dismantles the concrete wall with the hand crusher while regulating its height and its incidence angle. Then developed assistance machine is not changed in basic work form. It reduces a loads and the number of workers. And it is able to operate on the scaffold. Therefore the machine has to satisfy the following conditions.

- It can support weight of a crusher completely.
- It can move a horizontal plane and a perpendicular plane freely.
- It can regulate an incidence angle of the crusher to the concrete wall.
- It can be folded for being put on an elevator

From these conditions, a basic model of the machine is established. A horizontal joint arm composed of multiple links is connected to an electric forklift and a crusher is put on the leader. It was enabled for the machine to move a working space freely.

Furthermore, arranging a pitch axis carried the mechanical balancer (Mechanical Gravity Canceller), which Morita *et al.* [16] developed, in the leader, it is enabled to regulate the incidence angle. And also, setting a double joint and arm length, it is enabled to fold the machine in width at the same level as the forklift. A general view, the DOF and the length of the machine's basic model are shown in figure 2, 3 and table 1 respectively.

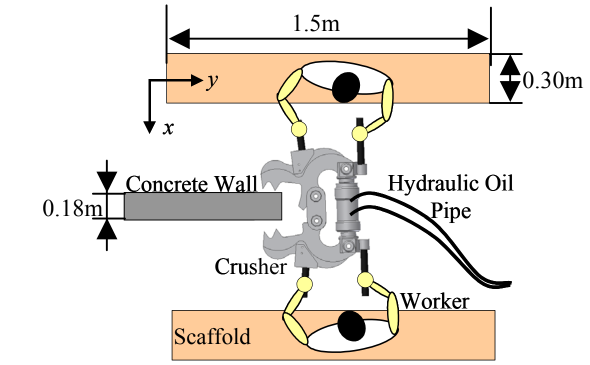


Fig.1 Work Environment without The Assistance Machine

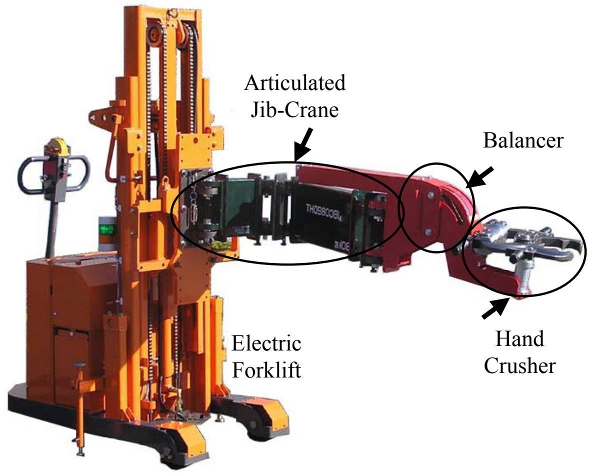


Fig.2 The Basic Model of The Machine

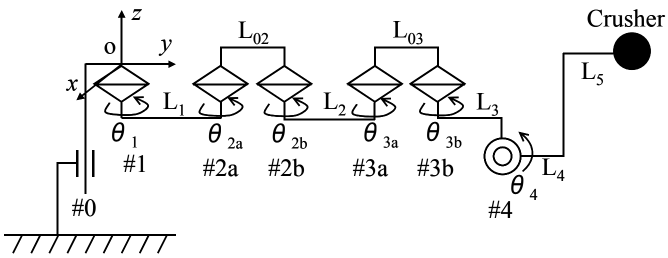


Fig.3 The Machine's DOF

Table1 Length Parameter of The Machine

	L1	L02	L2	L03	L3 +L4+L5
Length[mm]	320	142	640	142	647

3. AN ASSESSMENT METHOD

3.1 Interaction of The Assistance Machine and A Worker

The assistance machine consists of seven non-drive joints. A worker holds the machine directly for operation so that it is necessary to be considered an interaction of the assistance machine and a worker. In this paper, it is assumed that operability of the machine improved by incorporating viscosity resistance in joints.

Operability is analyzed about the straight-line movement that is parallel to the scaffold. Then it is written in the former chapter, a worker operates on the scaffold. Moderate viscosity resistance is available for operation [17][18]. In this paper, it is anticipated that a straight-line movement operability of the machine improved by incorporating viscosity resistance in joints. Therefore relations of the machine and a worker in the crusher movement are defined as figure 4.

$\boldsymbol{v}$: End-point Velocity
$\dot{\boldsymbol{\theta}}$: Angular velocity
$\boldsymbol{\tau}$: Joint torque
$\boldsymbol{F}$: End-point Force
$\boldsymbol{J}$: Jacobian-Matrix
$\boldsymbol{B}$: Coefficient of Viscosity matrix

Subscripts *m* and *h* express the assistance machine and a worker, respectively.

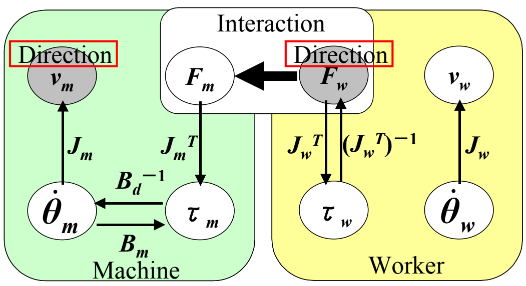


Fig.4 Interaction The Machine and A Worker

Manipulability Ellipsoid [8] is utilized as a general conception of the operability that represents a direction ingredient. Therefore at first analysis about the machine and a worker each, was done by applying Manipulability Ellipsoid. Next, combination of both ellipsoids to lead the operability considered interaction by paying attention to end point force.

3.2 Mobility Ellipsoid for The Assistance Machine

Viscosity resistance of joints of the assistance machine is changed to regulate the operability. The ellipsoid, which expanded a method of a Manipulability Ellipsoid, is suggested to analyze a change of operability for the work direction that occurred by change of viscosity resistance. This is defined as a Mobility Ellipsoid. A derivation procedure of a mobility ellipsoid is shown below. Joint torque $\boldsymbol{\tau}_m$ becomes expression (1) where joint viscosity of the machine is considered to be $\boldsymbol{C}_m = (\mathrm{diag}(C_1, C_2, \cdots, C_n))$. $\boldsymbol{B}$, which is viscosity coefficient in Mobility Ellipsoid, is defined expression (2) when based on the case that there is non-viscosity resistance. $\boldsymbol{E}$ is an identity matrix here. There for end-point velocity $\boldsymbol{v}_m$ is defined as expression (3). An Ellipsoid drawn by a feasible end point velocity vector in a range of joint torque $\|\boldsymbol{\tau}_m\| \le 1$ is a mobility ellipsoid. A major axis direction of the ellipsoid was defined as a manipulability direction, and an angle deviation between a work direction and a manipulability direction was defined as α.

$$\boldsymbol{\tau}_m = \boldsymbol{C}_m \dot{\boldsymbol{\theta}}_m \quad (1)$$

$$\boldsymbol{B}_m = \boldsymbol{E} + \boldsymbol{C}_m \quad (2)$$

$$\boldsymbol{v}_m = \boldsymbol{J}_m(\boldsymbol{\theta}_m)\boldsymbol{B}_m^{-1}\boldsymbol{\tau}_m \quad (3)$$

3.3 Manipulating Force Ellipsoid for A Worker

A Manipulating Force Ellipsoid is used as analytical technique of the direction that is easy to operate for a worker. This ellipsoid is perpendicular to the Manipulability Ellipsoid, and distribution of end-point force $\boldsymbol{F}_w$ is included.

Operability is analyzed in "eight degree of freedom (the waist and the arms)," which is the degree of freedom of a worker in total. A major axis direction of a Manipulating Force Ellipsoid is defined as a manipulating force direction. Here, it is supposed that the same torque can be shown in each joint to simplify the analysis (Figure5).

$$\boldsymbol{F}_w = \boldsymbol{J}_w(\boldsymbol{\theta}_w)^T \boldsymbol{\tau}_w \quad (4)$$

3.4 Workability Ellipsoid for A Work

The ellipsoid, which considered an interaction of the assistance machine and a worker, is proposed. From a result of a preliminary experiment, it was confirmed that force was given by the right hand mainly to the work machine during operation. Therefore it is supposed that operation was performed only by the right hand in analysis of this report.

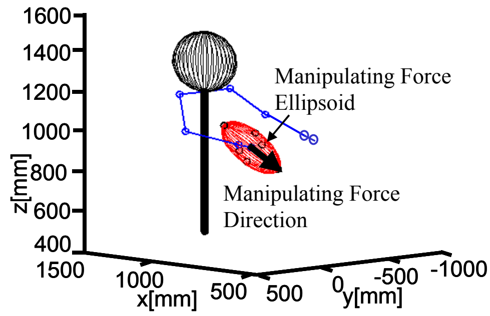


Fig.5 Manipulating Force Ellipsoid of A Worker

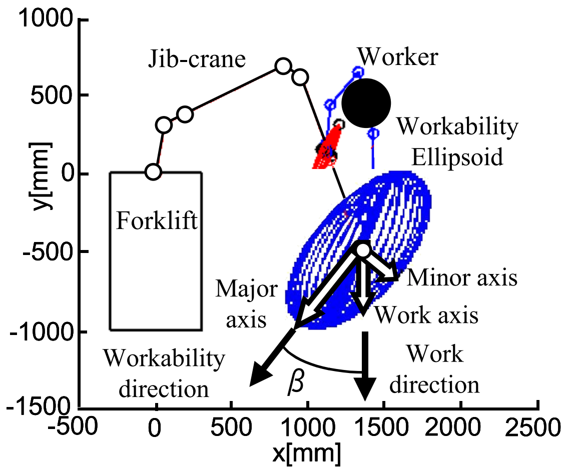


Fig.6 Workability Ellipsoid of A Work

Added force to the machine end point $\boldsymbol{F}_m$ is rearranged to the end point force of the worker $\boldsymbol{F}_w$, and end point velocity $\boldsymbol{v}_m$ shown under the force of the worker hand is demanded (expression (5)(6)).

$\boldsymbol{F}_w$ is a set of a Force vector based on a Manipulating Force Ellipsoid, and the combined ellipsoid considered the interaction of a worker and the machine as the projective transformation is formed. The direction, is easy to do the work, is shown by the radius size of the ellipsoid (Figure6).

After all, it is thought that work efficiency rises if a major axis direction and a work direction agree because it is easy to give force in a major axis direction, and the machine is easy to work. On the other hand, a burden grows big when a work direction agrees a minor axis direction so that it is not easy to put force either the machine is hard to move.

In addition, it is defined an angle deviation between a work direction and a direction of the combined ellipsoid major axis as β. Combined ellipsoid is defined as Workability Ellipsoid.

$$\boldsymbol{v}_m = \boldsymbol{J}_m(\boldsymbol{\theta})\boldsymbol{B}_m^{-1}\boldsymbol{J}_m(\boldsymbol{\theta})^T \boldsymbol{F}_m \quad (5)$$

$$\boldsymbol{v}_m = \boldsymbol{J}_m(\boldsymbol{\theta})\boldsymbol{B}_m^{-1}\boldsymbol{J}_m(\boldsymbol{\theta})^T \boldsymbol{F}_w \quad (6)$$

A radius of the ellipsoid is distribution of the velocity that can be shown to each direction, and it is not a standard of operability for movement to one direction. Therefore effective ellipsoid shape has to be examined for the operability to one direction.

Then three following indexes are set for the ellipsoid shape, it is thought contribution is big with one direction movement.

(1) Angle deviation β between a work direction and a workability direction is smallest.

(2) A radius to a work axis for a radius to a major axis (i.e. *P*) is largest.

(3) A radius to a minor axis for a radius to a major axis (i.e. *Q*) is greatest.

Because viscosity resistance of a joint is decided, it is thought that operability based on these three indexes can be improved.

4. A METHOD OF EXPERIMENT ANALYSIS

An experiment method, which inspects operability, is described in this section. As for the experiment, a subject steps on 30cm in width, 40cm high, a scaffold of 150cm in length, and operation of "coming and going": 1m forwards to a work direction and stands still and 1m backwards, shall be performed. A grip of "Jib-Crane L_3" and "the crusher top" is grasped during operation. Six axial force sensor (BL AUTOTEC. LTD.) was carried in a grip part, and it is enabled to measure the force distribution in work. A sensor grip(R) is focused on here. (Figure7) Both tropism disk dampers (Fuji Latex Co., LTD) are incorporated to create viscosity resistance in joint parts. Four kinds of disk dampers are rearranged, and combination of each viscosity resistance is examined for appropriate operability. These characteristics are shown in table2.

For the easiness, vibration of added force form the operation starts till it stops, and size of force, which except for the work direction during operation, are considered as an assessment item from force sensor data. And it is confirmed by sensory test by QDA method.

5. AS A RESULT OF ANALYSIS AND EXPERIMENT

5.1 Decision of The Assistance Machine's Basic Posture

Two kinds of operation postures such as figure8 are nominated for basic operation posture of the assistance machine. As for these posture, the following characteristics are expected.

(Ⅰ) : There is little influence of a crush piece at the time of a forklift movement, and the use in small space is possible.

(Ⅱ) : Operation is thought to be intuitive and a forklift transportation are easy.

There is a Manipulability Ellipsoid in each posture figure9. Comparison the posture (Ⅰ) with (Ⅱ), it is confirmed that an ellipsoid radius for the work direction (α) is bigger, and a volume of the ellipsoid is bigger. On this account the machine posture of (Ⅰ) is set as basic posture.

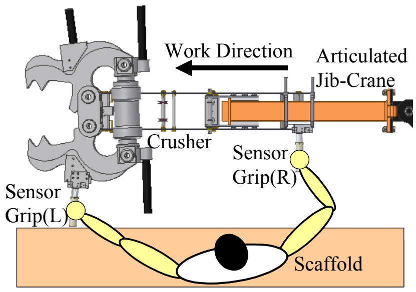
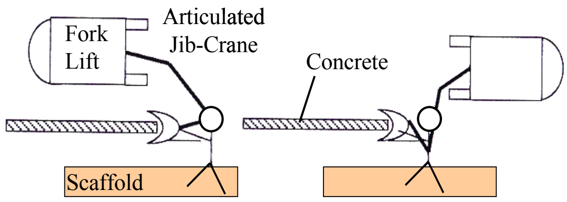
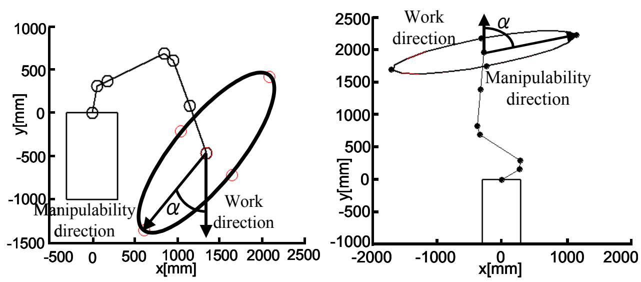


Fig.7 Operation Posture



Posture (Ⅰ) Posture (Ⅱ)

Fig. 8 Posture of The Machine



Posture (Ⅰ) Posture (Ⅱ)

Fig.9 Manipulability Ellipsoid

Table2 Characteristics of Dampers

Disc damper (type)	Characteristics
A	$0.224\dot{\theta}+1.43$
B	$0.721\dot{\theta}+2.79$
C	$1.05\dot{\theta}+3.54$
D	$1.18\dot{\theta}+5.28$

Table3 Body Size

	Shoulder	Upper arm	Forearm	Hand
Length	240mm	280mm	250mm	80mm

Table4 Combination of Viscosity

Index＼Joint	#1	#2a	#2b	#3a	#3b
(1)	--	D	D	D	D
(2)	--	D	D	--	--
(3)	A	D	D	--	--

Table5 Average Index Parameter

Index\Parameter	β	P	Q
Non-Viscosity	49.3	0.501	0.351
Index (1)	33.9	0.469	0.308
Index (2)	51.6	0.639	0.483
Index (3)	57.0	0.602	0.484

5.2 Result of The Analysis

From basic posture, the Workability Ellipsoid was analyzed and each "worker and machine" posture was examined. In addition, "the Disk damper" spoken earlier was used for viscosity resistance of a joint, and the most suitable placement was demanded.Based on body size shown in table2, an operation posture of the worker was analyzed. It is supposed that manipulating force is shown only by the right hand as described in former chapter.

It is confirmed that the Workability Ellipsoid shape becomes good for operability when distance between grips is 600mm and the right grip is in front of a body trunk. In addition, it is also confirmed that the Ellipsoid shape is different greatly by the posture (figure 10).

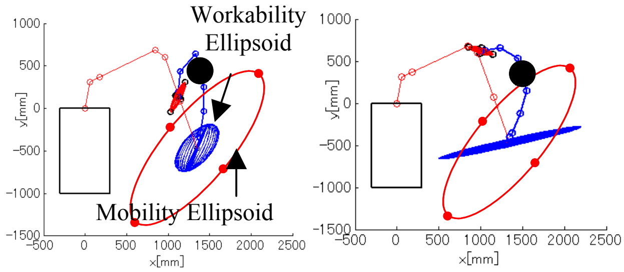
Each placement of viscosity, which adapt in each index, is decided from the average of the values β , P and Q when the work machine was moved from 0mm to -1000mm in y direction. Placement of viscosity resistance, the average of indexes in this case and the Workability Ellipsoids are shown in table4, 5 and figure 11 respectively. In addition, the machine moves to minus y direction further, the angle deviation β, the ratio of a major axis and a minor axis become bigger, so that a more fall of operability is expected. Then the movement from -500mm to -1,000mm is focused on, but the placement of viscosity resistance is the same.
An experiment is performed based on this result. The result of the experiment is shown in the next passage.

5.3 Result of The Experiment

Each posture of "the work machine and a worker" is decided by the operation posture analysis and the analysis of index (1) (2) (3), so that viscosity resistance is incorporated in each joint. An inspection of the Workability Ellipsoid and the indexes is done by an operability assessment.
The operation experiments are done about operation posture of a worker in cases of the distance between grips are 600mm and 900mm.Manipulating force added in the case of each is shown in figure 12.

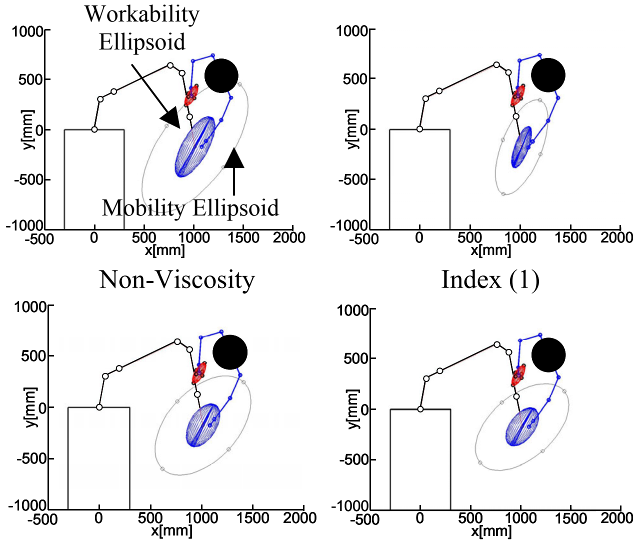
Focusing on the difference of distance between grips, size of force except a work direction is smaller and the adding time of manipulating force is shorter in the case of 600mm than that of 900mm. On this account manipulating force is reflected to the operation efficiency. In addition, this is confirmed from a result of sensory test shown in figure13. From these result the Workability Ellipsoid is proper.

The distance between grips assumed to be 600mm from a result of the foregoing paragraph. The force except for the work direction had the smallest contribution in the case of index(1). It was confirmed that comparing pattern 2 from the others, force Fy (i.e. the work direction of figure 14) was bigger on peak, and time convergence was earlier. On this account, it can be said that index (1) transmits the force to an operation direction efficiently. In addition, the force given to an anti-work direction at the time of stop was small, with an aspect of stability was good. Also in the



Between grips 600mm Between grips 900mm

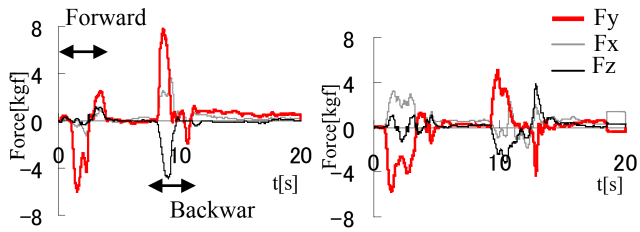
Fig.10 Workability Ellipsoid



Non-Viscosity Index (1)

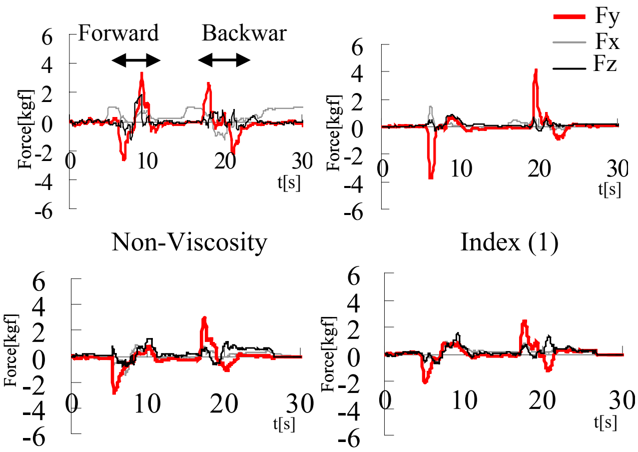
Index (2) Index (3)

Fig.10 Workability Ellipsoid



Between grips 600mm Between grips 900mm

Fig.11 Manipulating Force



Non-Viscosity Index (1)

Index (2) Index (3)

Fig.13 Manipulating Force

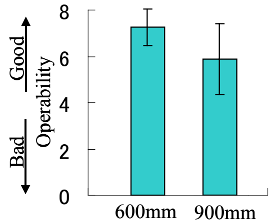


Fig.12 Sensory Test

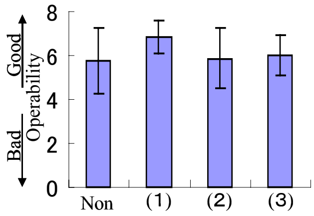


Fig.14 Sensory Test

result of sensory test, a tendency, which assumes that index (1) was easy to operate (shown in figure 15), is got, so that it was estimated that the angular deviation β contributes to the manipulability the most.

6. CONCLUTION

For operability improvement of the assistance machine, both a worker and the machines were considered. And the machine structure and operation posture analysis, evaluation and examination are performed. Summary of results provided in this article are as follows.

(1) With a general idea of a Manipulability Ellipsoid, initial placement that showed superior operability in a progress direction, of both the forklift and a articulated jib-crane were decided.

(2) The structural condition of the assistance machine and a force which generated from a human posture were combined, and the Workability Ellipsoid was suggested. By using this ellipsoid, operability assessment method was proposed.

(3) The grip placement that could convert the worker's force into the most effective experience of the assistance machine was examined. An inspection experiment was performed, and an appropriate range of distance between grips was derived.

(4) From the analysis of Workability Ellipsoid, the most suitable viscosity resistance was determined. The result added force and sensory test, primal index β is clarified.

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