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Design of a machine which rotates hoist elements around its vertical axis

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Abstract

On construction site hoist elements are rotated by the hands of assembly workers. This work is dangerous. To get better working circumstances, the elements can be rotated by a machine. On the principle based on Newton's third law "action and reaction" there is designed and built a machine. The result of the design process is that the principle of action and reaction works for light and small elements. For a short period of time the machine can withstand the wind forces by heavy and sizeable elements. How long this period has to be must be researched. Should this period be too long then other principles might to be considered.

1. INTRODUCTION

The Steering Committee Small-scaled Mechanisation on the construction site in The Netherlands (PKMB) has given the Building Research Institute TNO and the Eindhoven University of Technology TUE the task to develop a machine with which heavy and sizeable hoist elements can be rotated around its vertical axis.
PKMB will improve the working conditions (health, well-being and safety) of the workers on the construction site and without loss of productivity. To reach these goals research centers develop, optimize and promote small-scaled mechanisation tools within the industry. The result is usually a prototype that shows that the idea for an improvement works.

2. PROBLEM

More and more buildings consist of heavy and sizeable products: wall, roof and floor panels. These products are assembled with a crane and workers. The assembly workers now have to carry out physically demanding and dangerous work when they rotate loads with their hands or with a rope.
The health and safety inspectorate demand that workers be tied to the building by a safety line or insist that they work behind safety-rails. These two factors inhibit efficient working practice. Figure 1 shows the need to rotate elements.

3. POSSIBLE SOLUTIONS

The elements to be hoisted have to be rotated by a machine and not by the hands of the assembly workers. Such a machine can work on various physical principles. Some of these principles are:

- jet propulsion [1];
- gyroscop;
- reaction forces in the hoisting cables [2];
- action and reaction.

4. CHOSEN SOLUTION

For the design of the machine there is taken into account the goals of PKMB chosen for the principle of action and reaction[3]. This principle is based on Newton's third law:
"If a body exercises a force on another body, then the force on this body is as large, reversed and in the same line as the force of the first body".
The body is the hoisting element and the other body a flywheel. To rotate these bodies torque is required. According to Newton's second law is the size of the torque:

Torque	=	Moment of inertia	*	angular acceleration
M [Nm]	=	J [kgm^2]	*	"phi [rads^{-2}]

To show the working of the principle between a hoist element and a wheel, a simple prototype has been built. See figure 2.

5. EXISTING IDEAS AND MACHINES

In 1965 Lawrence Lawton received a patent of the United States Patent Office for an apparatus for orienting a suspending load [4]. He used a flywheel to get a torque to rotate a load. The Swede Paul Anderson got in 1978 a Dutch patent for an apparatus with two flywheels [5]. Also Smit Slikkerveer in The Netherlands deposited in 1978 and 1979 ideas based on action and reaction for public by the Dutch patent office [6] [7].
End seventies brought HOLEC in The Netherlands a machine on the market to handle sea containers. This machine was based upon the principle of action and reaction. The weights of the machines varied between 530 and 3500 kg.
At this moment the machines are not to be sold because other principles to handle sea containers are being developed.
An idea to win back energy by braking the flywheel is deposit by Nagron in The Netherlands [8]. Peiner in Germany got in 1989 a Dutch patent for a machine to rotate big loads on a crane [9].
There exist some ideas, but hardly machines on the market which can solve the assembly problems.

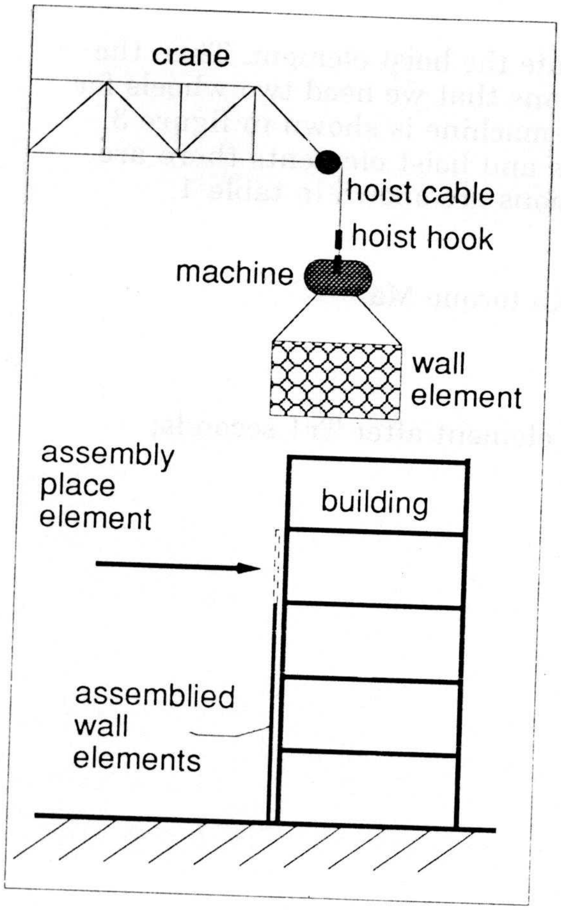

Figure 1. The machine had to rotate the wall element before assembly.

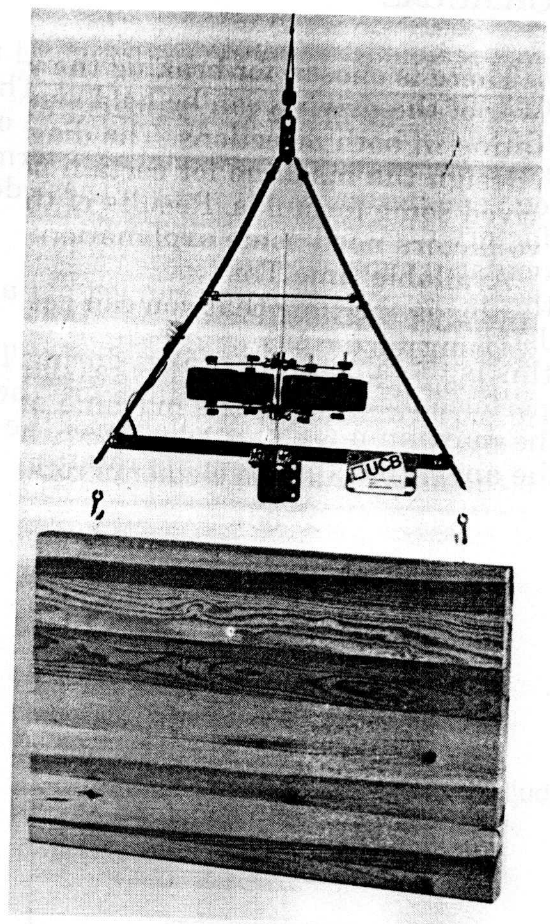

Figure 2. Photo of a simple prototype which shows the working of action and reaction between an element and flywheel.

6. PERFORMANCES OF THE MACHINE

The rotation performances depend on the parameters of the machine and hoist element.
The rotation performances are:
- the average angular velocity of the hoist element without wind force;
- the time to bring a certain angular velocity back to zero without wind force;
- the time to hold the angular velocity on zero with wind force.

The parameters of the machine are:
- the moment of inertia of the wheel (Jw);
- the maximum of the angular velocity of the wheel ('phi w max);
- the shaft power of the wheel (Pw).

The parameters of the hoist element are:
- the weight (Ge);
- dimensions: length, width and height.

7. FORMULAS

There is chosen for braking the wheel to rotate the hoist element. Then the power of the driving can be held small. This means that we need two wheels for rotating in both directions. The diagram of this machine is shown in figure 3. To design the machine for certain performances and hoist elements there are derived some formulas. Results of these derivations are shown in table 1.
Two factors need some explanation:

- Available time Tb:
  this is the time that you can get out a certain torque Ma.
- Using factor Vf:
  this is the amount of brakes during Tb.

The performances of the machine are then:

- the maximum angular velocity of the hoist element after Tr1 seconds;
- the angle that the elements rotates.

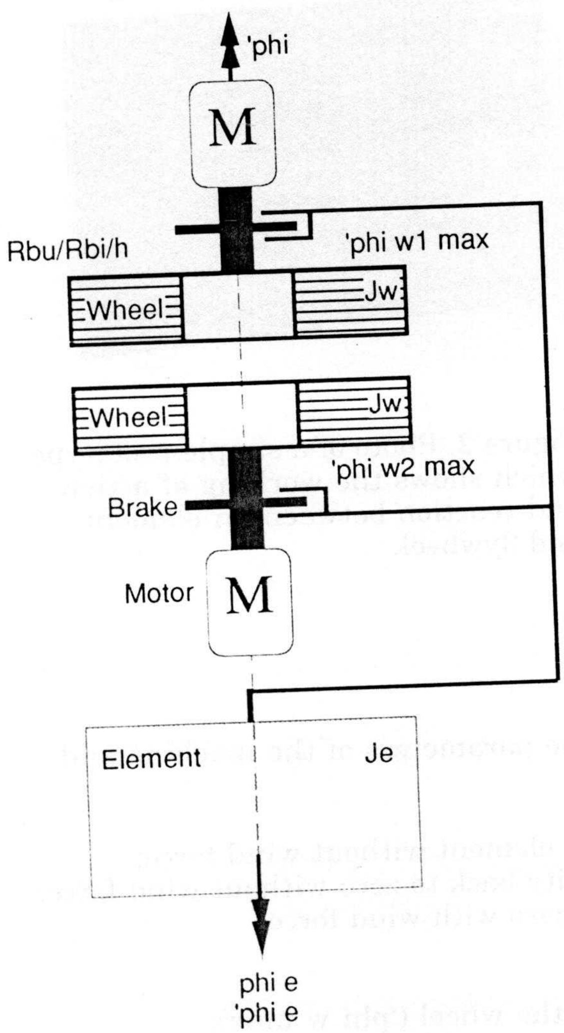

Figure 3 . The diagram of the machine with two flywheels

Table 1.
Formulas action and reaction

Description	Symbol	Dimension	Formulas
Wheel:			
Outer radius	Rbu	m	
Inner radius	Rbi	m	
Height	h	m	
Weigh	Gw	kg	=7900*3,14*(Rbu*Rbu -Rbi*Rbi)*h
Moment of inertia	Jw	kgm^2	=Gw*0,5*(Rbu*Rbu+ Rbi*Rbi)
Max transverse velocity	Vw max	ms^{-1}	
Max angular velocity	'phi w max	$rads^{-1}$	=Vw max/Rbu
Max revolutions per min	Nw max	$revmin^{-1}$	=60*'phi w max/2/3,14
Time to reach Nw max	To	s	
Shaft power	Pw	watt	=Jw*('phi w max)^2/To
Driving torque	MW	Nm	=Jw*('phi w max)/To
Element:			
Weight	Ge	kg	
Lenght	b	m	
Moment of inertia	Je	kgm^2	=Ge*b^2*/12
Ratio Je/Jw	R	-	=Je/Jw
Available time	Tb	s	
Brake torque	Ma	Nm	=Jw*'phi w max/Tb
Using factor	Vf	-	
Using time	Tr1	s	=Tb/Vf
Max angle velocity element after Tr1	'phi e max	$rads^{-1}$	=Ma*Tr1/Je
Max rev per min element after Tr1	Ne max	$revmin^{-1}$	=9,5*'phi e max
Angle element after Tr1	phi e Tr1	rad	=Ma*Tr1^2/2/Je
Angle element after Tr1	alpha e Tr1	degrees	=phi e Tr1*360/2/3,14

8. HEAVY AND LARGE HOIST ELEMENTS

Calculations have been made of an element with the following parameters:
- length: 7200 mm
- height: 3600 mm
- weight: 10000 kg

There is chosen for a steel flywheel with an outer radius of 500 mm, an inner radius of 350 mm and a height of 100 mm.

According to Genta [10] there are some restrictions as to the maximum transverse velocity. In this case we chose 40 ms^{-1}.

The results of the calculations are:
- To give the wheel the maximum angular velocity in 60 seconds you need an shaft capacity of 6286 watt.
- The ratio between the inertia moment of the element and the wheel is 733.
- The available time to brake is one second and brakes one time.
- The maximum revolutions to a minute is one.
- The angle that the element rotates is 3·313 degrees.

In these calculations the influence of wind forces has not been considered.

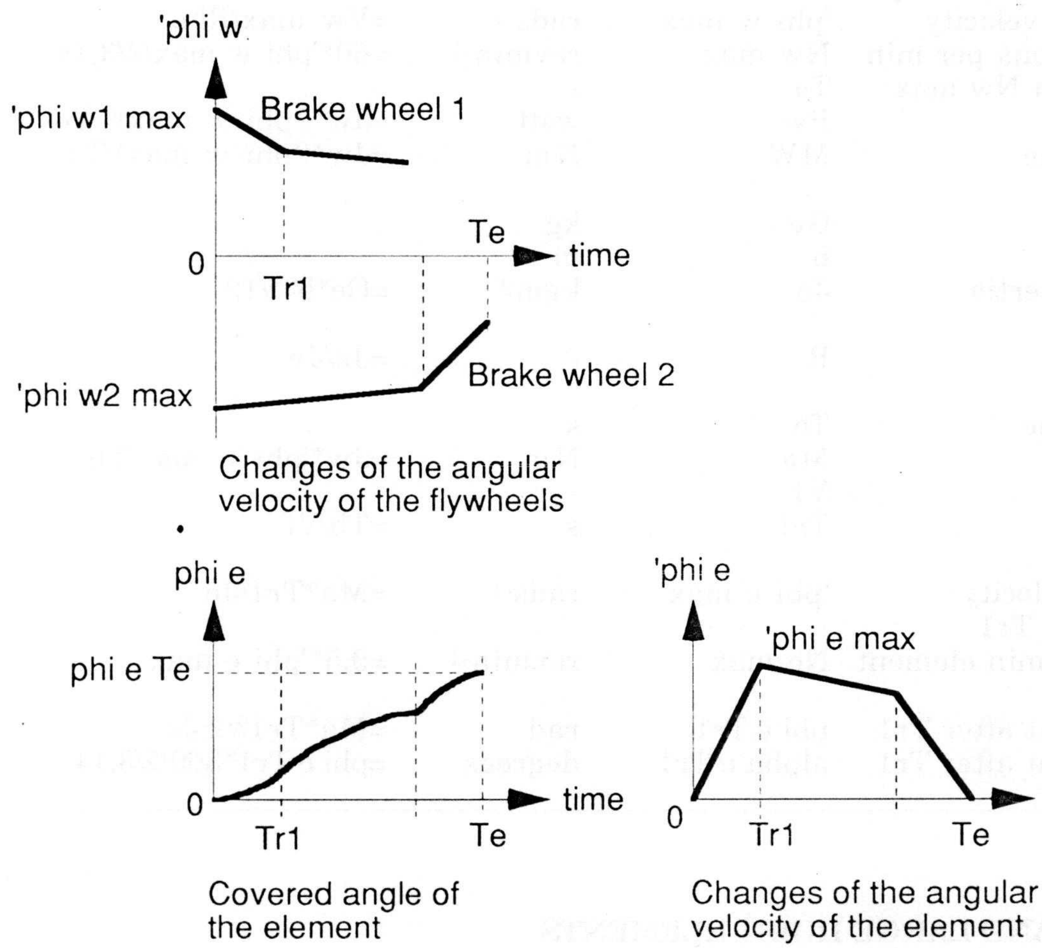

Figure 3. Behavior of the flywheels and element in time.

phi e	: covered angle element
'phi e/w	: angular velocity element or wheel
Tr1	: brake time wheel 1
Te	: end of rotating

9. WIND FORCES

To hold the angular velocity of an element on zero by wind forces a worker can do this by his hands with a force of 300 N during some minutes [11]. By the element described in paragraph eight means this, that the worker can exert a torque of 1080 Nm. The machine can bring up this torque about four seconds. Probably this is too short. Empirical data on the construction site will give more information what time is necessary.
The Dutch norm NEN 2018 says that the loading on the hoist is 0·03 of the weight. By our element means that a force of 3000 N on the hoist cable. What force the assembly worker had to bring up is unknown.

10. PROTOTYPE FOR LIGHT AND SMALL ELEMENTS

To get more experience with the physical principle of action and reaction in practice there a prototype has been built for a lighter and smaller elements with the parameters:
- length: 1200 mm
- width: 400 mm
- height: 1000 mm
- weight: 800 kg

There is chosen for two flywheels of steel with an outer radius of 250 mm, an inner radius of 150 mm and a height of 75 mm. The maximum transverse velocity is 36 ms^{-1}. By experiments with the prototype the machine needs about 10 seconds to rotate 90 degrees. For assembly work is this sufficient. The influence of the wind forces by small elements are a multiple smaller. For a photo of this prototype see figure 5.

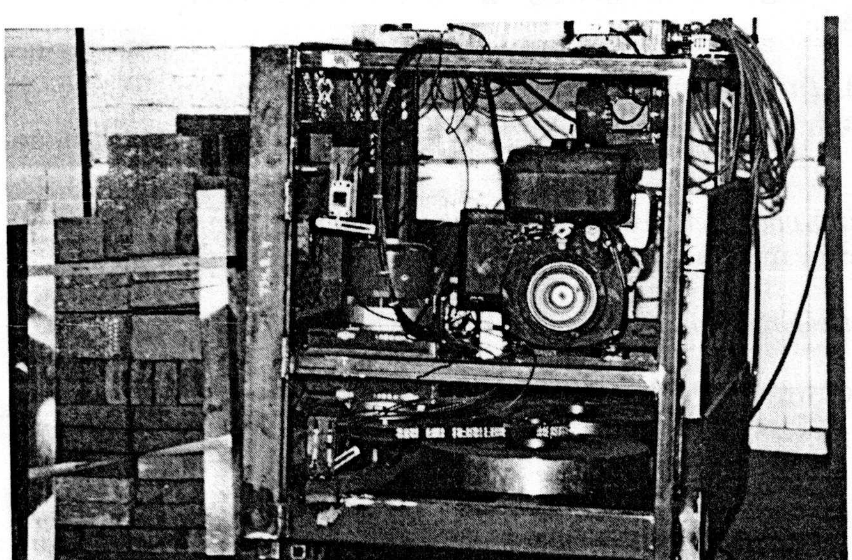

Figure 5. Prototype for light and small elements.

11. RESULTS

The result of this design process is that the principle of action and reaction for light and small elements works. Depending on the time that the machine can withstand the wind forces also heavy and sizeable elements are possible but how long that period is, must be researched. Should this period be too long then other principles might have to be considered.

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