Hiroprucci 4

Jhr Mr P. A. VAN BUTTINGHA WICHERS

NOTARIS

TE 'S-GRAVENHAGE

AFSCHRIFT

van een akte van depot ten behoeve
van B.V. NERATOOM.

Akte d.d. 29 april 1980.

KONINKLIJKE NOTARIËLE BROEDERSCHAP

Heden de negenentwintigste april negentienhonderd tachtig compareerde voor mij, Meester DIRK JAN GERRITSEN, candidaat-notaris, wonende te 's-Gravenhage, als plaatsvervanger van - Jonkheer Meester PETRUS ADRIANUS VAN BUTTINGHA WICHERS, notaris ter standplaats 's-Gravenhage: ----------------------

de Heer Meester Age Jan Ritsma, candidaat-notaris, wonende te Voorburg, volgens zijn verklaring handelende als mondeling lasthebber van de te 's-Gravenhage gevestigde besloten vennootschap met beperkte aansprakelijkheid: B.V. NERATOOM. --

De comparant verklaarde voor en uit naam van zijn last- - gever te deponeren ten einde onder mijn minuten te doen bewaren een technisch rapport bestaande uit éénentwintig (21) bladzijden, hetwelk aan deze minute is gehecht. -----------

De comparant is mij, notaris, bekend. -------------------

------------------- Waarvan akte in minuut -----------------

Verleden te 's-Gravenhage, ten dage in het hoofd dezer -- vermeld. --

Na de zakelijke opgave van de inhoud van deze akte aan -- de comparant en zijn verklaring van de inhoud daarvan te --- hebben kennis genomen en op volledige voorlezing van de akte geen prijs te stellen, is deze akte onmiddellijk na de be- - perkte voorlezing door de comparant en mij, notaris, ondertekend. ---

(Getekend) A.J. Ritsma, D.J. Gerritsen. ------------------

UITGEGEVEN VOOR AFSCHRIFT

Jhr. Mr. P. A. VAN BUTTINGHA WICHERS NOTARIS TE 's-GRAVENHAGE

b.v. neratoom	Rapport Verslag nr. ____________ Werkopdracht	Datum The Hague Plaats 15-07-1975

Bestemd voor afd.	Auteur Dr.Ir.G.G.Hirs	Afd.	Aant. blz.	Bijl.
Kategorie	Ondertekening	Fiat afdeling	Goedkeuring	
Behoort bij werkopdracht	Project	Archiefnummer	Projectnummer	
Verdeling:	Onderwerp: Windmills			

Samenvatting:

Conventional Windmills.

Conventional windmills can be built in unit sizes greater than now usual. It is said that 100 m diameter windmills on higher than 50 m towers could generate about 3 MW on average and 5 MW maximum. Such windmills might generate "cheap" energy if the investment costs were below 5.000.000 DFL and if reasonably low maintenance and operating costs were achievable. The drawback of electricity generation by windmills will be the large fluctuations in output due to the large fluctuations in wind speed.

No economic, long term energy storage system seems to be available. It might be argued that in a purely capitalist society the problems associated with fluctuations in wind speed can be overcome by introducing an electricity price that is inversely proportional to the wind speed!

However, in all other societies, electricity prices should be reasonably low and reasonably stable. To achieve this, conventional windmills should be modified in the following respects:

1. power production fluctuations smaller in amplitude and extending over shorter time periods;
2. higher power density per unit size;
3. greater unit sizes;
4. simplified design.

The first modification, mentioned above, probably is of primary importance.

New Design Concepts.

Fluctuations.

1. The objective of the main design concept should be to suppress power production fluctuations and to shorten periods between two fluctuations as much as possible.
   As power production is proportional to the third power of the wind speed, windmills should produce power in locations where windspeeds are more or less equal.
   This can be done by:
    1. finding a location where such conditions prevail and building a windmill there;
    2. building a movable windmill and operating this mill in locations where wind speeds are more or less equal.

The first solution is practical but not very economic
There are places where wind speeds do not vary much but these are too far away from regions where the energy should be used.
Therefore, windmills for electricity for the U.K. are expected to be located in the Irish Sea and those for Holland, Belgium and Germany in the North Sea.
Therefore the only alternative is to move windmills vertically. This would enable operation at selected altitudes where windspeeds are favourable and more or less equal to the windmill's design windspeed.

Conclusion in regard to the suppression of power production fluctuations.

Windmills should be capable of operating at selected altitudes where the wind speed is favourable.

As altitudes of more than 100 m should be reached, windmills mounted on a tower or similar static construction are not feasible.

The only alternative is to use the wind for supporting windmills. Operating such windmills would be similar to flying a kite but also to carry power from the kite-windmill to earth, see fig. 1.

Power Density.

2. The density of the power generated by a windmill varies with the radius and most of the power will be generated at the outer radii, see fig. 2.

   It can be said that a conventional windmill has a big hole in the centre draining more than half of the power offered by the wind. The obvious solution is to design a windmill on which the vanes do not rotate over their entire orbit, but are free to translate over the whole or part of their orbit, see fig. 3.

   Methods should be considered how to move the vanes from one side to the other in the design of fig. 3.

Conclusions in regard to power density.

the greatest power density in windmills is obtained if the vanes translate over the whole or part of their orbit.

Greater unit sizes.

3. For conventional windmills, greater unit sizes are being considered as power output increases with the square of a typical size at a given tip speed of the windmill.

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Wind mills should be capable of operating at selected altitudes where the wind speed is favourable. As altitudes of more than 100 m should be reached, windmills mounted on a tower or similar static contruction are not feasible.
The only alternative is to use the wind for supporting windmills. Operating such windmills would be similar to flying a kite and the string should not only serve to mechanically locate the kite but also to carry power from the kite-windmill te earth, see fig. 1.

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3. For conventional windmills, greater unit sizes are being considered as power output increases wth the square of a typical size at a given tip speed of the windmill.

By doing so, a lower investment per unit power output can be reached:

1. added value and other effort for building a windmill increase with increasing power output. However, the increase is less than proportional;
2. similarly, the infrastructure connecting individual units and the grid, shows a smaller number of branches and is, therefore, less complicated;
3. design refinements can more easily be introduced in large units than in small units.

As far as tensile stress in vanes due to centripetal forces are concerned, these are independent of the unit size and depend only on the tip speed of the vane and these have no influence on the quantity of material used or on the cost both per unit power output. However, aerodynamic bending forces on the vanes and on the supporting structure (tower) are proportional with the square of a typical size at a given typical speed of the windmill and these can be counteracted only by increasing the material quantity to the third power with unit size.
This would mean that, for scaling up conventional windmills, the quantity of material per unit power production would rise more than proportional with unit size and possible other savings in investment cost per unit power production would wholly or partly be offset depending on size.
This increase in cost per unit power production applies not only to the vanes but also to the supporting structure/tower. Thus conventional windmills can not be scaled up indefinitely, they have an optimum size which might well be in the order of 100 m diameter.
Bending moments and the additional material to cope with it, can be greatly reduced by supporting all components (tower, vanes) by strings and cables. By doing so, the potential to reduce cost per unit power output by increasing size, is extended towards greater size ranges. A side view of a windmill with supporting strings is given in fig. 4.

Conclusion with regard to greater unit sizes.

Savings in investment cost per unit power output by increasing size of conventional windmills, is counteracted by additional cost of material per unit power output for coping with increasing bending moments.
Additional material can be prevented by supporting vanes and towers by strings or cables, thereby reducing bending moments.

Simplified design.

4. Windmill designs should be simplified and conclusions from the foregoing sections should be incorporated without introducing basic design complications.
   A conventional windmill consists of a number of rotating vanes on a shaft, a device converting mechanical energy into a different kind of energy, c.q. electricity and a supporting static structure (tower). It should be added at this stage that the converter to whatever kind of energy (including electricity) is a heavy piece of equipment and should be mounted down te earth.

   a. the first conclusion with respect to the suppression of power production fluctuations is not in contradiction with a simplified design. Indeed, the requirements to be able to operate a windmill at selected altitudes including those above 100 m, eliminates the possibility of mounting the windmill on a high tower. This is a major design simplification. However it should be realised that operating a windmill as a kite on a string will cost a large research and development effort. It is expected that the aerodyna- of such windmills and their construction can be based on experience in NLR, Fokker, TNO etc. A major difficulty will be the transfer of the mechanical energy generated from the mill and its conversion.

-7-

It would appear difficult to convert mechanical energy into electricity high up in the air and to transfer the electricity to the earth via the cable. Due to its heavy weight, equipment to convert energy should be located on the earth. On the other hand it would appear difficult to transfer mechanical energy from the windmill to earth via the cable.
If such mechanical energy is generated by a windmill with rotating vanes and is offered as torque from a rotating shaft, it should be converted to some form of reciprocating energy as no appreciable torque can be tranferred via a long string or cable.

b. The second conclusion with respect to the power density expressed a preference for translating vanes and not for rotating vanes. This conclusion now appears to be in agreement with a simplified design as mechanical energy from a translating vane is not offered as torque on a rotating shaft. A design in which the two conclusions are unified is shown in fig. 5.
For the sake of simplicity one vane is shown. The vane is moving upwards during the first part of the orbit and unwinds a cable from a shaft. The weight/lift force ratio is taken sufficiently small. The combination of lift force minus weight and drag force determine the pull on the cable. The combination of vane and cable should also have a low drag to lift ratio. By doing so the cable can be unwound from 10-100 m to 1-10 km. The power generated will be equal to the pulling force times the unwinding cable speed. Rewinding the cable should take place at an as small as possible energy loss and, therefore, an as small as possible drag force
A system where the pull on the shaft is continuous is shown in fig. 6.

Another variant is shown in fig. 7.
In fig. 8, a system is shown where the actual windmill is supported by a separate kite. It is typical of all designs that long vanes follow an orbit and that the motion is translationary.
The power density and the effective area are both great and it should be possible to build windmills with an effective area of say 1 km^2 generating 300-500 MW.

c. In the third conclusion it was said that bending moments should be kept as small as possible. By doing so it will be profitable to scale these windmills up to size ranges of 1 km. Bending moments are kept small in the designs of figs. 5-8 by dividing the load on a vane on a great number of cables, see fig. 5.

It is realised that the windmill designs of figs. 5-8 only give operating principles. Design details to be studied are:

a. orbit control of the individual vanes, including attitude angle control;
b. material selection;
c. conversion of mechanical to electrical energy with recoprocating cables.

P.S.

Fig. 9 shows how the functions of cables (supporting and power transmission can be seperated).

The main drawback is the extra resistance of the cables. However, the orbit of the blades can more easily be controlled and their attitude angles can probably be changed when necessary.

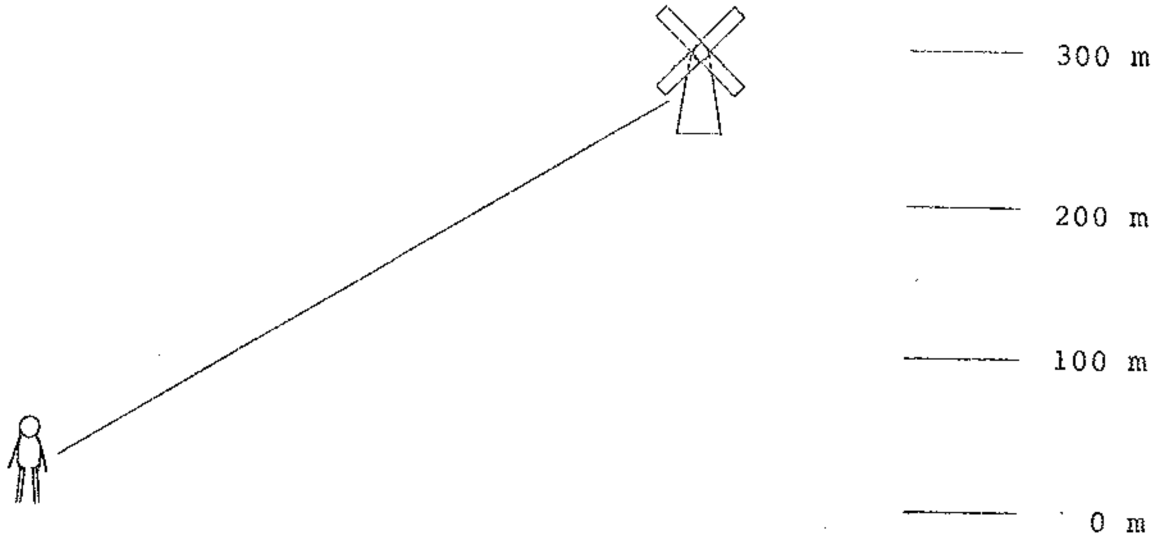

Fig. 1 Operation of windmills at selected altitudes.

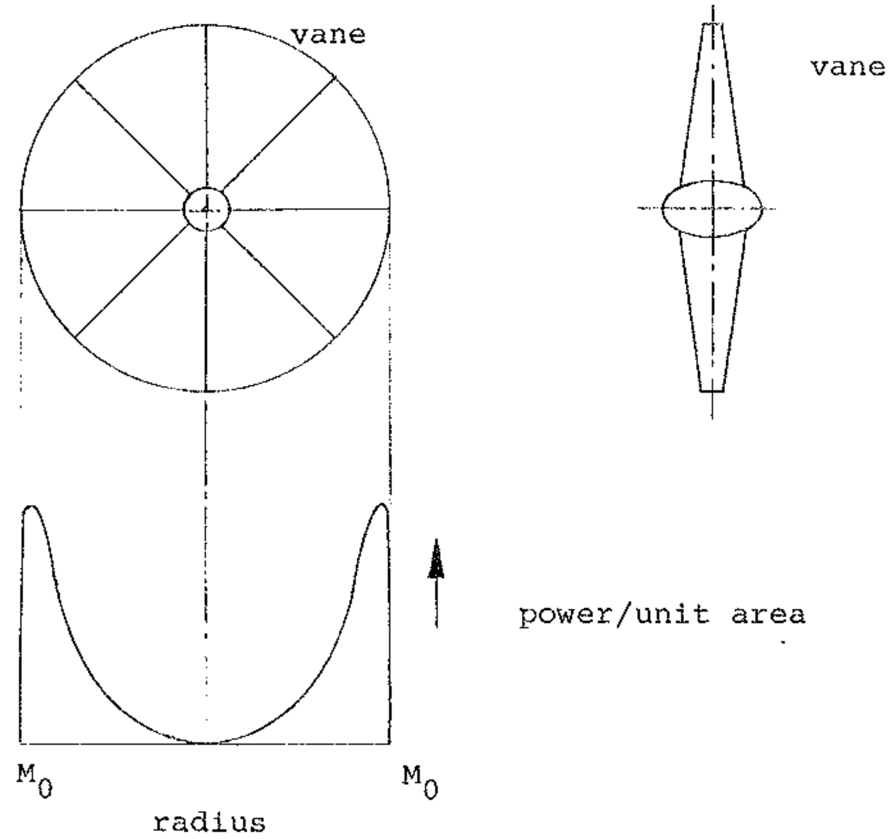

Fig. 2. Windmill with rotating vanes.

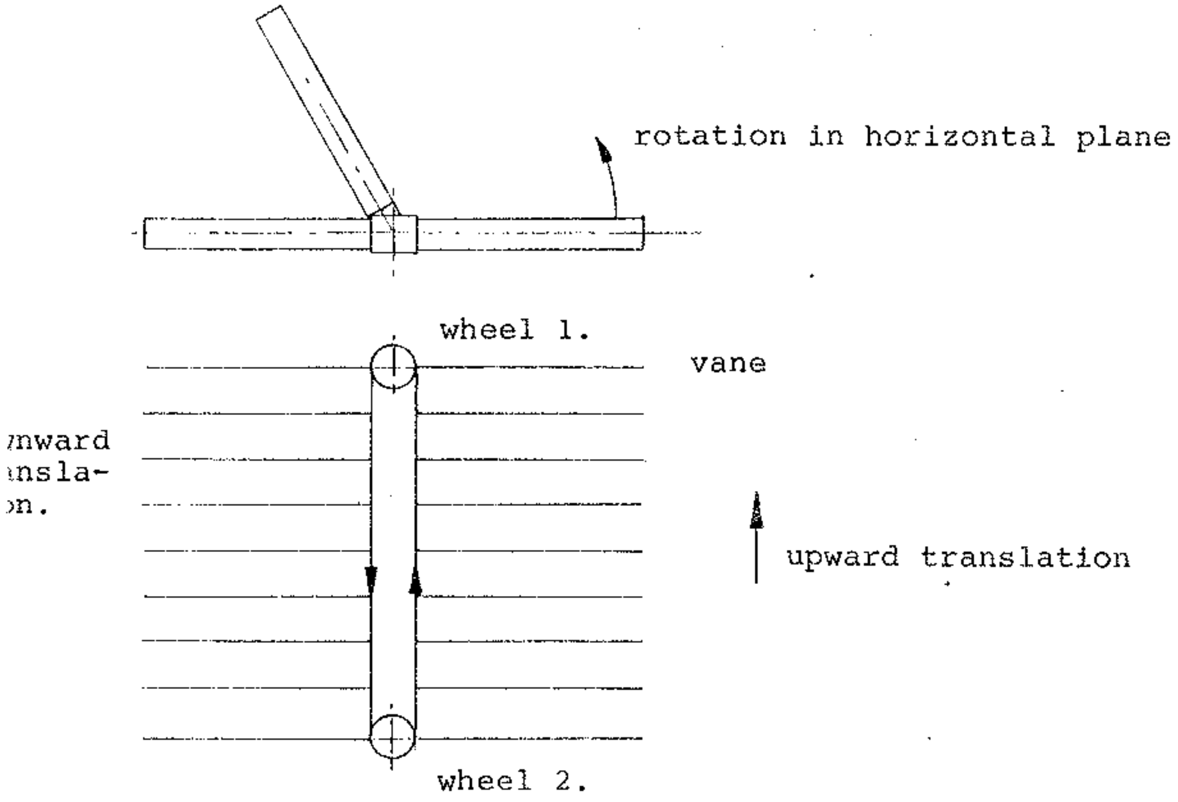

Fig. 3. Windmill with translating vanes

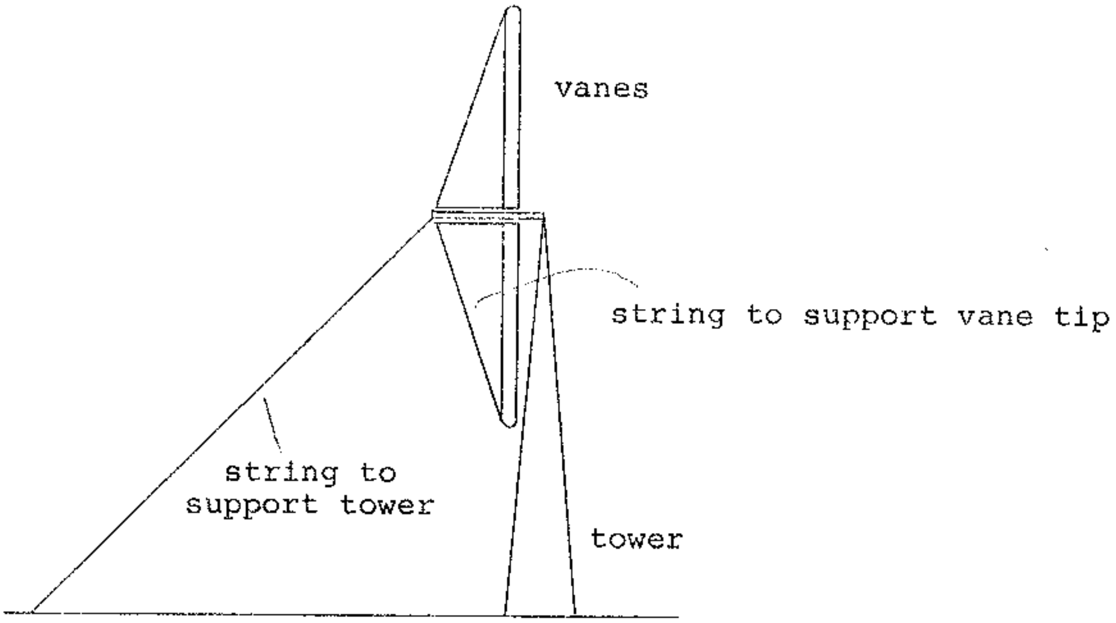

Fig. 4 Strings supporting vanes and tower

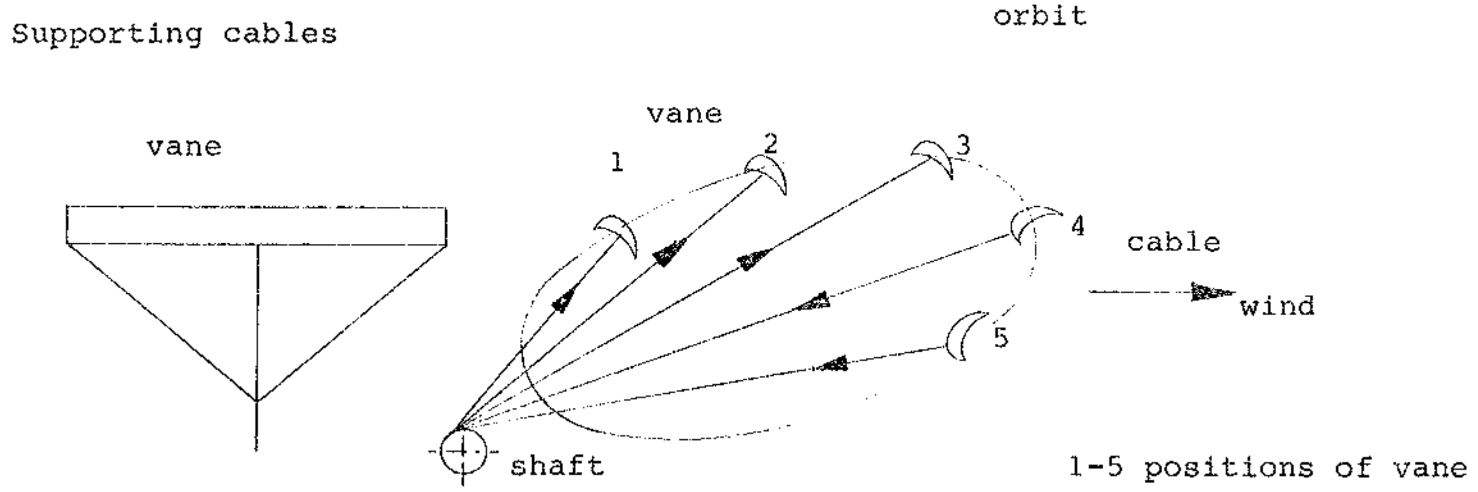

Fig. 5 Reciprocating cable, one-vane windmill

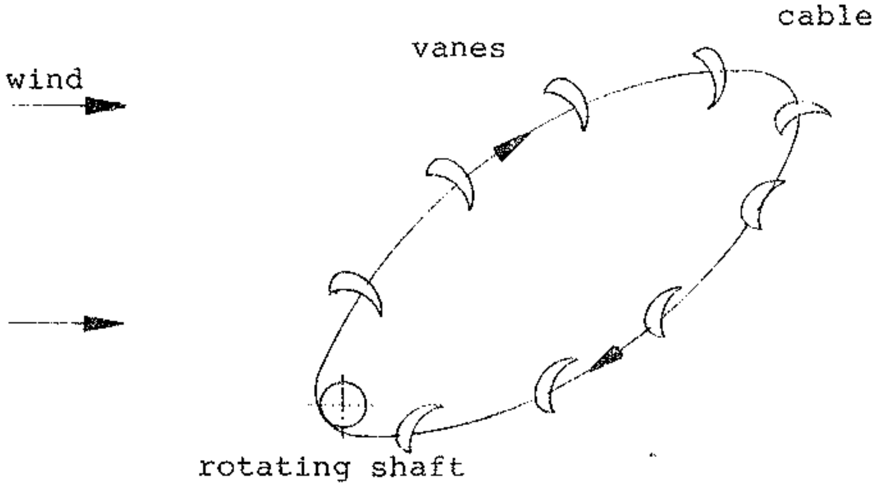

Fig. 6 Rotating cable, multi-vane windmill

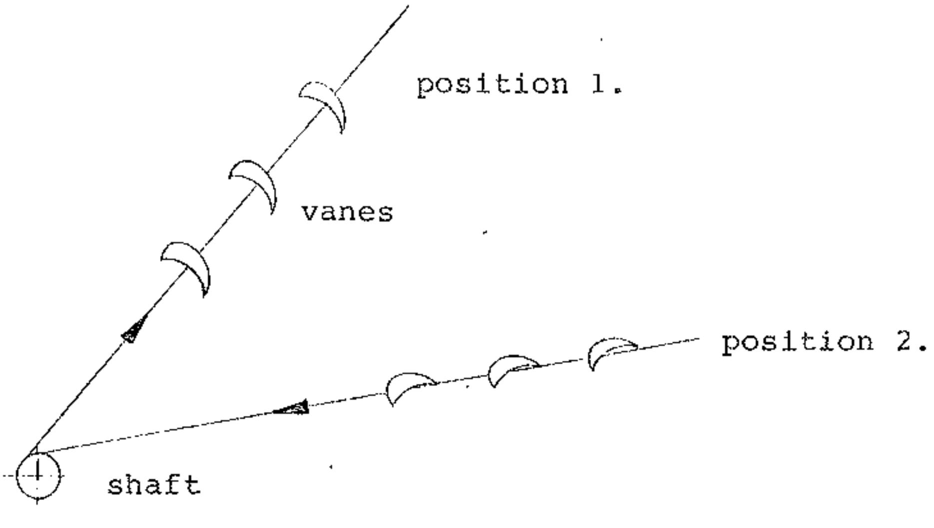

Fig. 7 Reciprocating cable, multi-vane windmill

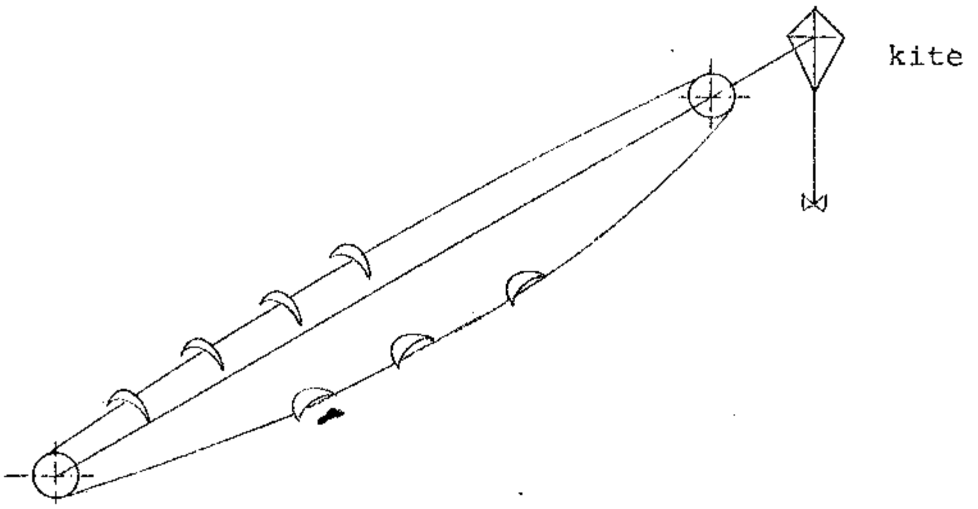

Fig.8 Rotating cable, multi-vane windmill, supported by kite.

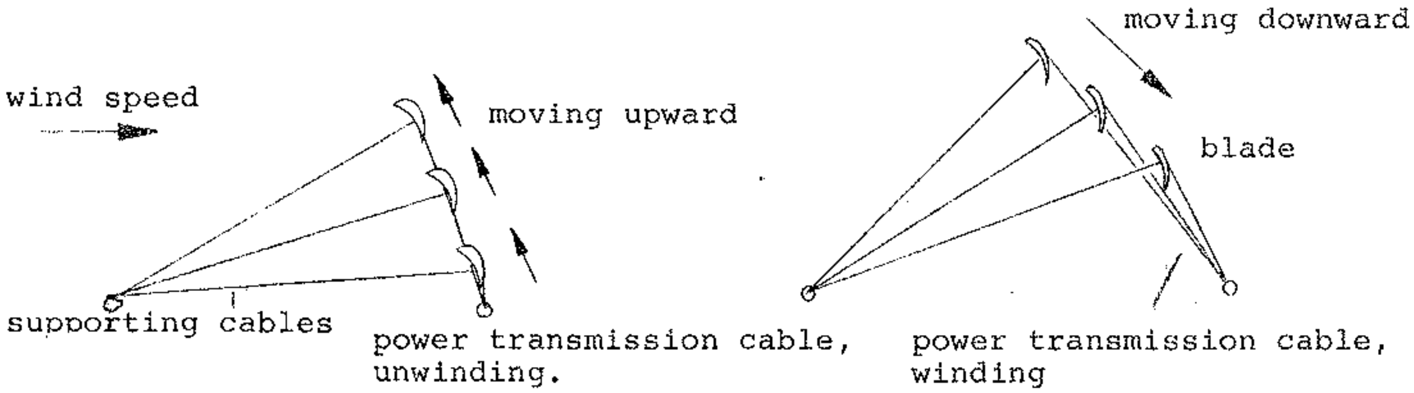

Fig.9 Functional separation between supporting and power transmitting cables.

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Preliminary calculations of kite-type windmills.

Samenvatting:

Introduction.

In fig. 1, a kite-type, translating windmill is shown.
The lefthand part of the figure shows a cross section of the blade, or wing, a string and a drum winding or unwinding the string.
Speeds v_1 and v_2 are components of the winding or unwinding speed $\dot{R}$ with respect to the drum.
The wind speed is v_o. Speeds v_{10} and v_{20} are speeds as seen by the blade. The instantaneous lenght of the string is R (radius). This indicates that the string can be seen as a radius in angular motion $\dot{\varphi}$ with the drum as centre point.

The righthand part of fig. 1 shows that each individual blade is operated from two drums. Strings are so arranged that only unidirectional forces of roughly equal magnitude are exerted on the blade. The arrangement of the strings resembles that for supporting a bridge-type structure. By doing so, bending moments in the blade are kept at a minimum and forces on the blade are perpendicular to it.
In the following attention will concentrate on the aerodynamics of the windmill shown in fig. 1. Equations will be derived for combinations of vertical and horizontal translating movements of the blade or multitudes thereof.

Power generated by kite-type, translating windmills.

In fig. 1., the lift force acting on the blade (L) is in the same direction as the string. The power generated is the product of unwinding speed and force L:

$$P = L\,(v_1^{\,2} + v_2^{\,2})^{\,0.5} \quad \text{or } P = L\dot{R} \tag{1}$$

where P power, L force, v_1 and v_2 components of the (un)winding speed $\dot{R}$.

The liftforce L can be expressed as follows:

$$L = c\,\rho(v_{10}^{\,2} + v_{20}^{\,2})\,A \tag{2}$$

where c = 0,25 for a minimum dragforce

ρ density

v_{10} horizontal velocity with respect to blade

v_{20} vertical " " " " "

A blade area

The dragforce acting perpendicular to L (in the same direction as the resultant of v_{10} and v_{20}) is assumed to be negligibly small.

The simplifying assumption that the dragforce is negligibly small, results in the following relationship between the speed components with respect to the drum and those with respect to the blade:

$$\frac{v_1}{v_2} = \frac{v_{10}}{v_{20}} = \tan\varphi \tag{3}$$

The relationship between the sets of speedcomponents in the coordinate system attached to the drum and the blade is as follows:

$$v_{10} = v_o - v_2 + \dot{\varphi} R \sin \varphi \qquad (4)$$

$$v_{20} = \quad + v_1 + \dot{\varphi} R \cos \varphi \qquad (5)$$

By inserting $v_2 = \dot{R} \cos \varphi$ in (4), $v_1 = \dot{R} \sin \varphi$ in (5) and subsequently, by inserting (4) and (5) in (3) a relationship for φ can be found.

$$\cos \varphi = \frac{\dot{R}}{v_o}$$

Speeds (4) and (5) can now be rewritten as follows:

$$v_{10} = v_o \left[\left\{ 1 - \left(\frac{\dot{R}}{v_o} \right)^2 \right\} + \frac{\dot{\varphi} R}{v_o} \left\{ 1 - \left(\frac{\dot{R}}{v_o} \right)^2 \right\}^{0.5} \right] \qquad (6)$$

$$v_{20} = v_o \left[\frac{\dot{\varphi} R}{v_o} \; \frac{\dot{R}}{v_o} + \frac{\dot{R}}{v_o} \left\{ 1 - \left(\frac{\dot{R}}{v_o} \right)^2 \right\}^{0.5} \right] \qquad (7)$$

After some reworking the following equation for the power reslts from (1)

$$P = c \rho \; A \; v_o^3 \; \frac{\dot{R}}{v_o} \left[\frac{\varphi R}{v_o} + \left\{ 1 - \left(\frac{\dot{R}}{v_o} \right)^2 \right\}^{0.5} \right]^2 \qquad (8)$$

The equation shows that no power is generated for the case that:

$$v_{10} = v_{20} = 0 \quad \text{or} \quad \frac{\dot{\varphi} R}{v_o} = - \left\{ 1 - \left(\frac{\dot{R}}{v_o} \right)^2 \right\}^{0.5}$$

In that case, the blade floats horizontally with the wind speed.

The equation also shows that power will be generated by unwinding the string for conditions where rotation is zero $\frac{\dot{\varphi} R}{v_o} = 0$:

$$P = c \; \rho \; A \; v_o^3 \; \frac{\dot{R}}{v_o} \left\{ 1 - \left(\frac{\dot{R}}{v_o} \right)^2 \right\} \qquad (9)$$

The optimum speedratio is $\frac{\dot{R}}{v_o} = 0.58 = \cos\varphi$.
Thus the unwinding speed should be 0.58 of the windspeed and the blade should rise at an angle of 54°.
For those wind conditions the power is

$$P = 0.385\ c \rho A v_o^{3}$$

Even more power could be generated if the blade rises vertically:

$$v_{10} = v_o \quad \text{and therefore,} \quad \frac{\dot{\varphi} R}{v_o} = \frac{\left(\frac{\dot{R}}{v_o}\right)^2}{\left\{1 - \left(\frac{\dot{R}}{v_o}\right)^2\right\}^{0.5}}$$

$$P = c \rho A v^{3} \ \frac{\frac{\dot{R}}{v_0}}{1 - \left(\frac{\dot{R}}{v_o}\right)^2}$$

The power does not have a theoretical maximum and this is due to the fact that drag has been neglected. However, a very high power can be expected to be generated for conditions where

$$\frac{\dot{R}}{v_o} \longrightarrow 1 \qquad \text{at } \varphi \dashrightarrow 0^0$$

extremely high rotational speeds of the string

$$\frac{\dot{\varphi} R}{v_o} \longrightarrow \infty$$

From conventional windmills it is well known that the higher speed ratios make it possible to extract te wind energy with the smallest number and area of blades. However, the aerodynamic properties of the blades should be excellent: low draft lift ratio. Nevertheless, speed ratios in excess of 10 are unpractical for several aerodynamic and mechanical reasons.

All this leads to the following conclusions:

1. The maximum power generated by blades can be estimated by inserting

$$\frac{\dot{R}}{v_o} = 1 \text{ and } \frac{\dot{\varphi} R}{v_o} = 10 \text{ in eq. (8)}$$

It follows:

$$P_{max} = 100\, c\, \rho\, A\, v_o^3$$

2. Such power can only be generated by blades moving vertically at speeds up to 10 times the windspeed and at low inclinations of the string. Vertical movements of up to 1 km. are envisaged. Thus, string lenghts of up to 5 km. should be contemplated.

3. The total available wind power is

$$P_{av} = 0.5\, \rho\, v_o^3\, A_v$$

where A_v is the vertical area to be covered by the moving blades.
In order to be able to extract this power from the wind by means of blades as mentioned sub (1), such blades (one or more) should have an area A that can be found by equating P_{max} and P_{av}:

$$\frac{A}{A_v} = \frac{0.5}{100\, c}$$

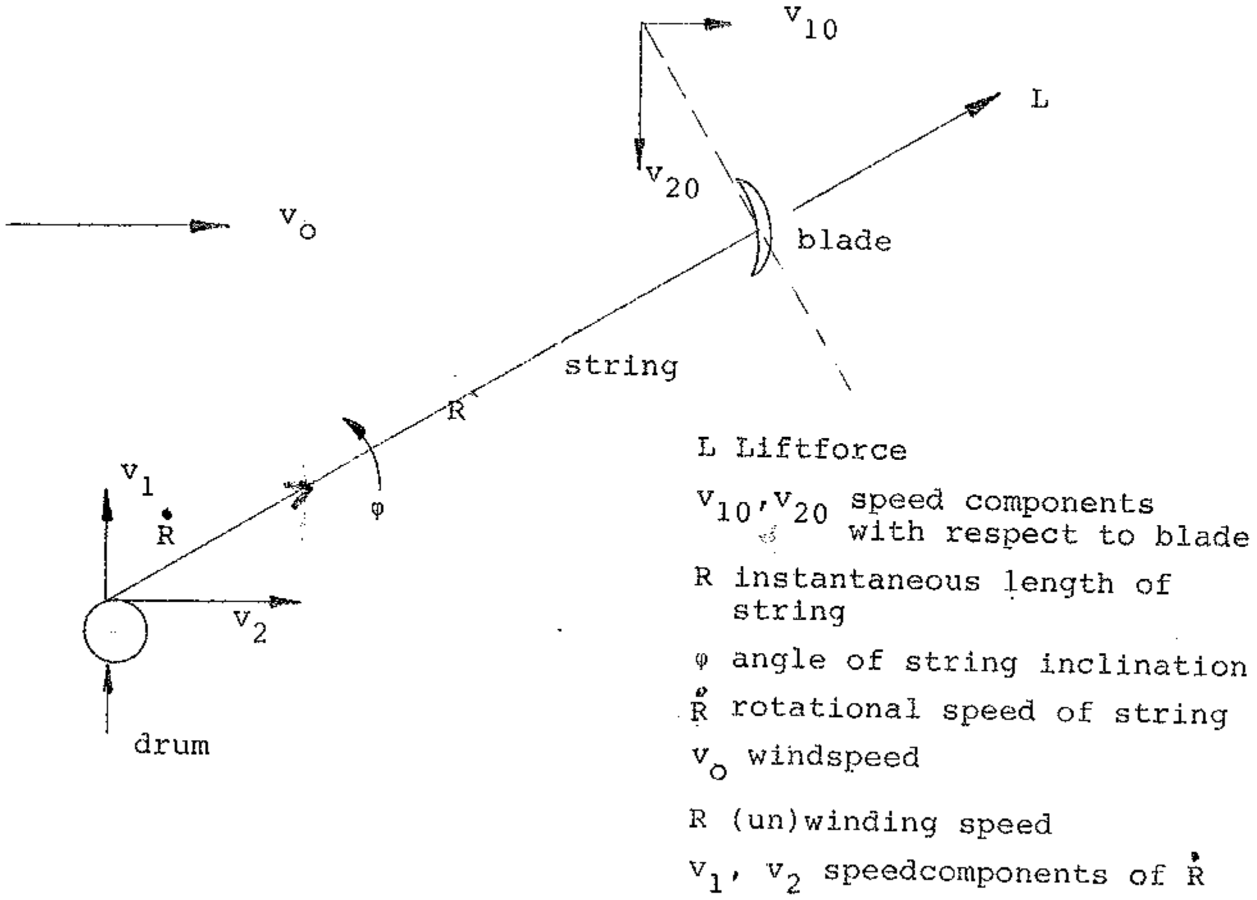
Good blades operating at a reasonably low drag-lift ($c = 0.25$) would show the area ratio to be:

$$\frac{A}{A_v} = 2.10^{-2}$$

This indicates that extracting the wind power from an area of 1 km^2 would require a total blade area of 2.10^{-2} km^2 or 2.10^4 m^2.

4. The total available power to be extracted from an area of 1 km^2 at a wind speed of 15 m/s is roughly 2000 MW. At an efficiency of 25 percent, the power generated could be 500 MW. The power density per unit blade area now becomes 25 kW/m^2.

5. The total material quantity can be related to the total blade area $A = 2.10^4 m^2$. The blade construction is light-weight and the average material thickness should be in the order of 10^{-3} - 10^{-2} m. Thus, the material quantity is 10 - 100 m^3. At a machining cost of 10^6 DFl. per m^3. The total cost would be 2.10^8 DFL.
   The investment cost per kW would be 400 DFl. This would appear to be low at first sight. However, these costs may not be compared with nuclear power costs as operating, maintenance and replacement costs of windmills can be expected to be appreciable. Nevertheless, there is some merit in further development of this windmill type.



L Liftforce

v_{10}, v_{20} speed components with respect to blade

R instantaneous length of string

φ angle of string inclination

$\dot{R}$ rotational speed of string

v_o windspeed

R (un)winding speed

v_1, v_2 speedcomponents of $\dot{R}$