EXTERNAL WIND EFFECTS ON FLOATING SOLAR CHIMNEY

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Abstract

The floating solar chimney (FSC) is a new invented technology by the author for constructing very tall solar chimneys for large solar turbine power stations (STPS).

The FSC can self-float due to its construction by double wall made by light enduring fabric, filled with lifting inflammable gas (NH_3,He).

The FSC can deflect due to its base construction and its accordion type folding lower part. Due to this construction the FSC can encounter effectively the external winds.

Assuming a Weibull statistics for local winds in the place of FSC's installation the annual average operating height, due to its deflection is calculated.

The invented FSC, made by a set of successive parts independently attached to its base and dynamically separated by appropriate isolation tubes, can encounter the wind 's velocity variation with altitude.

Key Words

Floating Solar Chimney, wind effects, Weibull

1. Introduction

In the paper of reference [1], a new idea for constructing very tall solar chimneys was presented. The effect by the increase of the height of the solar chimney has very important positive results.

It can be proved approximately that increasing the height of the solar chimney by a factor , the output power of its collaborating solar power station will be increased by a bigger factor .

The main cylinder of this new construction, patented as in reference [2], is a set of successive balloon tubes as shown in figure (1).

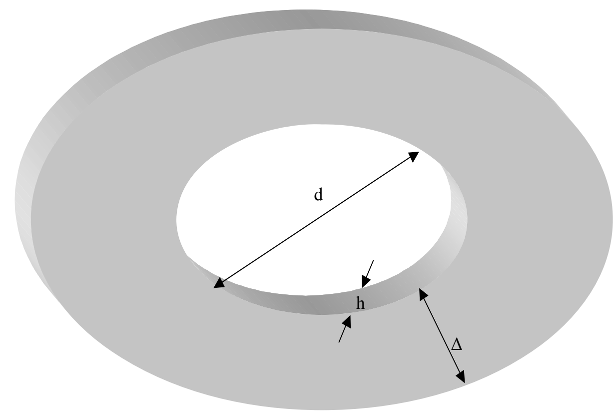

FIGURE 1

These balloon toroidal tubes can be separated by successive supporting rings ,one of which is shown in figure (2). These successive supporting rings made by Al or composite materials, can support the balloon tubes, in order to withstand the high operating sub pressure on the wall of the cylinder of the solar chimney.

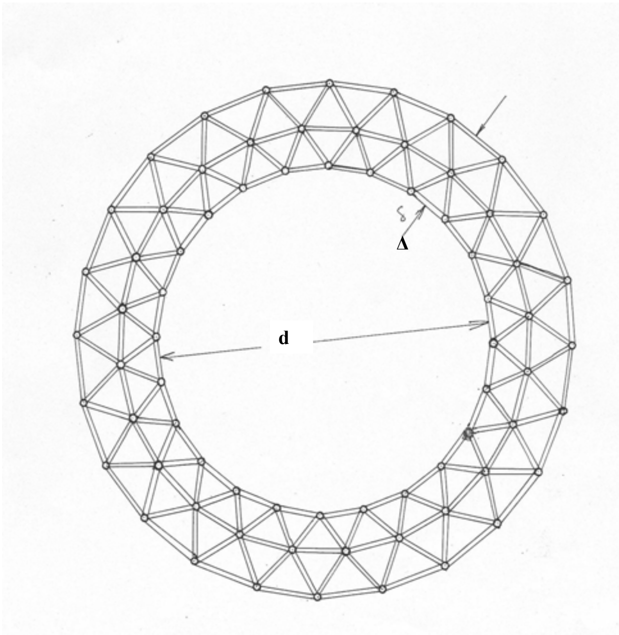

FIGURE 2

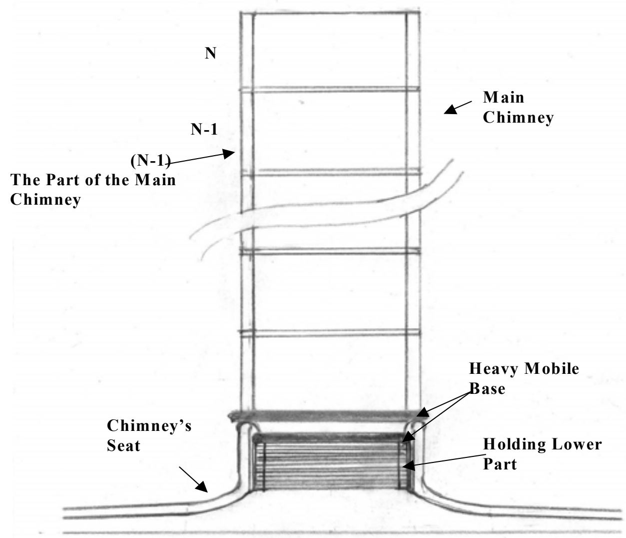

FIGURE 3

The balloon rings are filled with a lifting inflammable gas (NH_3,or He). The dimensions of the balloon tubes can be calculated in order their net uplift force by their internal lift gas to be greater than the overall weight of the balloon and supporting rings. This gives to the solar chimney the property of self-floating.

Thus this invented solar chimney is named Floating Solar Chimney (FSC).

The FSC is formed by several parts. Each part of the FSC is a set of successive balloon tubes and if necessary with intermediate supporting rings. These parts are separated by appropriate tubes, filled with environmental air entering and leaving freely from them, through appropriate valves. These intermediate isolation tubes separate dynamically the successive parts of the main cylinder of the FSC. Hence if there is a variation with altitude of the wind velocity, the differences in deflection angles of the successive parts will not effect dynamically each other.

The base of the FSC is a set of two major components as shown in figure (3):

- **A heavy mobile base**, on which the parts are attached separately. This heavy base is formed by two equally weighted rings, that compensate the net uplift force of the whole upper cylindrical balloon structure. The two rings are united through a very strong fabric. When the FSC is deflecting by the external wind effects, the rings of the heavy base are inclining while their strong fabric keeps the FSC on its place, on top of the leaps of the seat.
- **And a folding part** consisting by a set of successive tubes filled with free environmental air that is entering or leaving by them freely through appropriate apertures or valves,or strong fabric insulated externally. The tubes or the insulated fabric are fixed successively using intermediate supporting rings. This structure is working like an accordion, securing the continuity of the FSC when the FSC declines. Hence the warm air stream can not escape in the bottom of the structure, guided through the FSC to move towards the top of the FSC in order to escape to the upper layers of the atmosphere.

A solar turbine power station (STPS) has three major components

- A solar collector
- A floating solar chimney
- A set of turbo generators

For an STPS of 200MW it can be proved ,using the equations of reference [1], that could have an FSC (Filled with NH_3)of 3000m height and 100m internal diameter and 118m external diameter. The internal diameter could be progressively increasing from bottom to top from 100 m to 112 m, optimizing the operation of the STPS.

In the present paper it will be explained how the external winds are encountered by the flexible structure of the FSC, and what will be the effect on the operating height of the FSC due to its average deflection arising by the external winds.

The FSC could have 750 balloon rings of 4m height separated in 15 parts by 14 intermediate balloon rings of 4m height. Thus the FSC will have approximately a height of 3056 m. As it will be proved the operating height of the FSC will be slightly smaller.

2. Encountering external winds

The net uplift force (KA) for every balloon–ring and finally for the whole FSC is necessary in order the main cylinder of the FSC to take a normal position.

If external winds appear, that for the analysis following are assumed to be of constant direction and strength, the FSC will deflect from its normal position.

It is obvious that its angle of deflection is increasing with the wind speed and is decreasing with the net uplift force.

As shown in figure (4) the angle of equilibrium θ is approximately around the position where the drag force F_D, arising from the normal to the FSC component of speed, $\upsilon\cos\theta$, is equal and opposite to the normal to FSC component of net uplift force, $(KA)\sin\theta$.

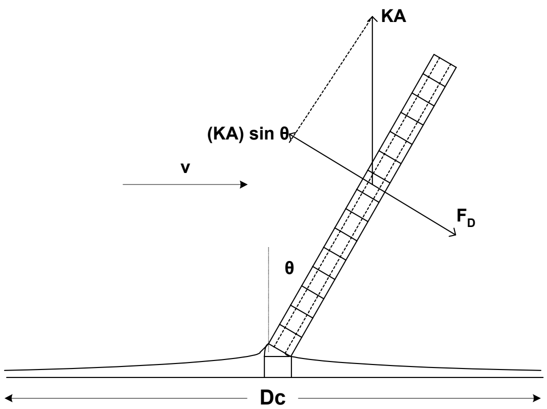

FIGURE 4
FSC under external wind with speed υ

We assume that FSC is constructed and filled with a lifting gas in a way that, the net uplift force of every part of it, is decreasing proportionally to the air density $\rho_{(Z)}$. Under this assumption because the drag force F_D is also proportional to the air density $\rho_{(Z)}$, the decline angle of every part, and the whole FSC, is independent of the altitude z.

The drag force per balloon-ring F_D is aproximately given by the relation :

$$F_D = C_D \frac{1}{2} \rho \cdot \upsilon_n{}^2 \left(hD_{out}\right) \quad (1) \quad \text{where: } \upsilon_n=\upsilon\cos\theta$$

The coefficient C_D depends on the Reynolds number $\mathrm{Re}_L = \dfrac{\upsilon_n D_{out} \rho}{\mu}$. It can be proved that for usual FSC diameters and air speeds υ_n ,$Re_L>10^7$ hence there is a turbulent air flow around the FSC, leading to $C_D\approx 0,3$ (see White [3])

For the initial balloon-rings $\rho_{(z=0)}\approx 1.16$ kg/m^3 and $d_{\varepsilon\xi}=d+2\Delta\approx 118$
Hence: $F_D\approx 0.3\times 0.5\times 1.16\times 4\times 118\times\upsilon^2\times\cos^2\theta$ i.e. $F_D\approx 82\ \upsilon^2\cos^2\theta$ Nt.

For the equilibrium deflection the normal drag force F_D should be equal with $(KA)\sin\theta$ hence:

$(KA)\sin\theta=82\ \upsilon^2\cos^2\theta$ (2)

Assuming that for $\upsilon=\upsilon_{MAX}=10$m/sec the angle of equilibrium is equal to π/3, where the operating height of the FSC will become half of the initial i.e. ≈(H/2) the following equality is derived :

$$(KA) = \frac{82\times 100\times\cos^2\left(\dfrac{\pi}{3}\right)}{\sin\left(\dfrac{\pi}{3}\right)} = \frac{82\times 50}{\sqrt{3}} = 2367\,Nt$$

Thus under this condition the net uplift force for the first balloon-ring (z=0), is equal to 2367Nt or 241.3kg. The net uplift force for the following balloon-rings must decrease following $\rho_{(z)}$. Hence for the FSC with H=3000m, d=100m. The total net uplift force will be

$$\sum KA \approx 750\times 241.3\times\frac{\rho_{av}}{\rho_{(z=0)}} \approx 156\,ton..$$

The choice of υ_{MAX} it depends on the average wind speed υ_{av} in the place of STPS. It is assumed that the wind obeys the Weibull statistic with Weibull Constant K_w, hence the probability for wind speeds bigger that υ_{MAX} is given by the relation :

$$P\left(\upsilon \geq \upsilon_{MAX}\right) = \exp\left[-\left(\frac{\upsilon_{MAX}}{C}\right)^{kw}\right]$$

$$\text{όπου } C = \upsilon_{av}\Gamma\left(1+\frac{1}{K_w}\right) \qquad (3)$$

For example if in the place of STPS and FSC the average wind speed is υ_{av}=3m/sec and K_w=2, the probability of $\upsilon>\upsilon_{MAX}$=10m/sec calculated by (3) becomes 7.1792×10^{-7}. This extraordinary small probability means that in a year, in this place, υ will become bigger than 10m/sec only for 22 sec. However the weibull statistic does not include the strong winds that may appear that do not effect average annual values.

If the filling of initial balloon-tube creates a net uplift force of 2367 Nt the relation (2) becomes:

$\lambda\sin\theta=\upsilon^2(1-\sin^2\theta)$ where $\lambda=(KA)/82\approx 28.9$. Hence the speed of wind υ and the angle of decline of FSC are connected with the relation $\upsilon^2\sin^2\theta+\lambda\sin\theta-\upsilon^2=0$ thus :

$$\sin\theta = \left[\frac{-\lambda+\sqrt{\lambda^2+4\upsilon 4}}{2\upsilon^2}\right] \qquad (4)$$

And the operating height of this FSC under the influence of wind with speed υ is equal to:

$$H_{(\upsilon)} = H\cos\theta = H\sqrt{\frac{-\lambda^2+\lambda\sqrt{\lambda^2+4\upsilon^4}}{2\upsilon^4}} \qquad (5)$$

For winds with $\upsilon > \upsilon_{MAX}$ the folding part, it is unfolded completely and the FSC and STPS stops to operate, however as was mentioned this is a very rare event.

The annual average operating height of the FSC is given by the following relation:

$$H_{av} = \int_{0}^{V_{MAX}} H(\upsilon)\left(\frac{Kw}{C}\right)\left(\frac{\upsilon}{C}\right)^{K_w-1} \cdot \exp\left[-\left(\frac{\upsilon}{C}\right)^{K_w}\right] d\upsilon \quad (6)$$

For Kw=2, υ_{av}=3, C=2.6587 και λ=28.9 . The operating height for the FSC of H=3000m, calculated by this relation (6) is equal to 2890.9m.

If the operating annual height of the FSC should be equal to 3000 m , 29 more balloon rings could be added of 4m height each, increasing the initial height of 3000m to 3116m. This could be achieved forming the FSC from 15 parts each having 51 balloon rings, and separated by 14 isolation tubes. In this case the net operating height will be $H_{av} = 2890.7\dfrac{3116}{3000} \approx 3002.5m$.

An alternative solution leading approximately to the same power output for the STPS could be to increase the area of its solar collector approximately by $\dfrac{3000-2890.9}{3000}100\% = 3.6\%$.

If in the place of installation of the STPS with the previous FSC the average wind speed is greater, for example υ'_{av}=5 /sec, for the FSC with λ=28.9 using the relation (3) and (6) we have C=4,4311m/sec,and H_{av}=2618m. In this case the operating height of FSC is decreasing by 12,7%.

From the previous paragraphs it is obvious that the annual average strong winds in the places where STPS will be instaled, are not favorable..

The effect on H_{av} of K_w of the winds'statistic in the place of STPS's installation is more mild. On figure (5) this effect is shown for υ_{av}=3m/sec and $1.2 \leq K_w \leq 3$.

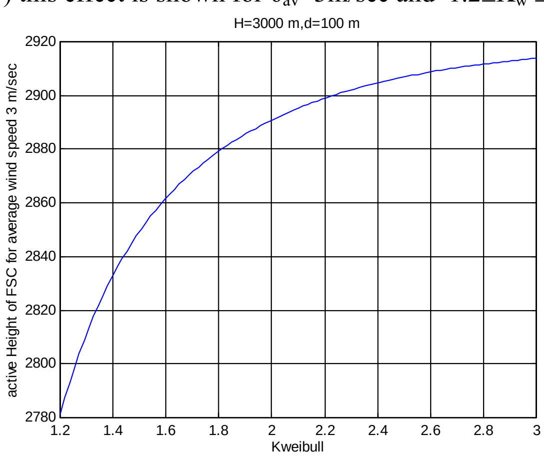

FIGURE 5

The normal force on the wall balloon rings is encountered by the intermediate supporting rings or the rigidity of the pressurized tubes. The pressure on the wall arising by the external winds is much smaller compared to the operational sub pressure acting on it.

The tangential component of the wind on FSC equal to υsinφ creates a shear force on it, smaller than F_D. This shear force has as an effect to create a moment around the point of equilibrium that is compensated by an opposite moment arising by the weight of the folding part of the accordion lower part of the FSC.

Hence the assumption that the angle of equilibrium of FSC is related to the wind speed by the relation (2) is almost accurate.

3. Encountering variable wind velocities with altitude

As it was already mentioned the FSC is a set of parts, each of which is a set of balloon lifting tubes and supporting rings. The successive parts are separated by intermediate isolation tubes, which are not filled with lifting gas.

These intermediate balloon rings have special valves permitting to the environmental air to enter or move out from them.

They separate the successive parts of the FSC dynamically. This means that the successive parts can move, up to a certain range, independently each other, without mutual interference.

This means that if the n[th] part is under the wind speed υ_n and the n+1 under the wind speed υ_{n+1}, the two successive parts will have different deflection angles. The difference of the angles of deflection will be given by the following relation (7) :

$$\Delta\theta_n = \arcsin\left[\frac{\left(-\lambda+\sqrt{\lambda^2+4\upsilon_{n+1}^4}\right)}{2\upsilon_{n+1}^2}\right] - \arcsin\left[\frac{\left(-\lambda+\sqrt{\lambda^2+4\upsilon_n^4}\right)}{2\upsilon_n^2}\right]$$

λ is assumed constant for every part of FSC, and for the FSC under consideration, it is equal to 28.9 .

For a perfect dynamic isolation of these two successive balloons the following relation must be valid:

$$\Delta\theta_n \leq 2\arcsin\left[\frac{\left(\frac{\Delta h}{2}\right)}{d}\right] \qquad (8).$$

For he FSC under consideration Δh=4m, d=100m hence $\Delta\theta_n \leq 0.04$.

Assuming that $\upsilon_n = \upsilon - \dfrac{\Delta\upsilon}{2}$ and $\upsilon_{n+1} = \upsilon + \dfrac{\Delta\upsilon}{2}$

The average wind speed is υ, and hence they will be approximately with an average deflection angle:

$$\theta = arc\sin\left[\frac{\left(-\lambda + \sqrt{\lambda^2 + 4\upsilon^4}\right)}{2\upsilon^2}\right]$$

The altitude of their mean points is 200×cosθ.

The difference Δυ for which $\Delta\theta_n$=0.04 divided by 200×cosθ, gives the maximum wind speed difference per m of altitude, for the dynamic isolation of he successive parts.

In figure (6) the maximum wind speed variation per m of altitude is shown, as function of the average wind speed in this altitude, for a perfect dynamic isolation of successive parts in this height.

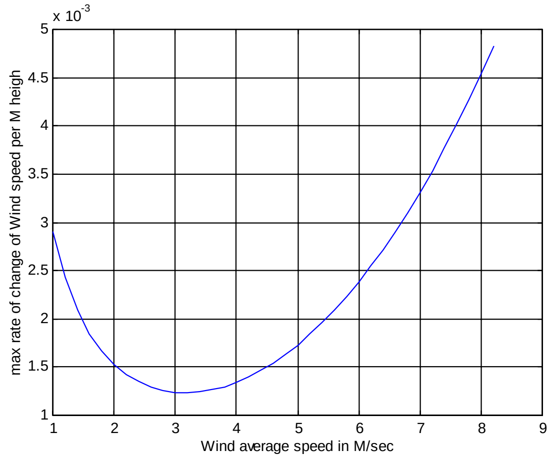

FIGURE 6

Assuming that FSC has Δh/d≈0.04, and that the wind speed near ground is $\upsilon=\upsilon_1$ (for the first part), this part will decline with an angle

$$\theta_1 = arc\sin\left[\frac{-\lambda + \sqrt{\lambda^2 + 4\upsilon_1^4}}{2\upsilon_1^2}\right]$$ and its mean point will have an altitude $h_1=h/2\times\cos\theta_1$,where h=200m is the height of each part of the FSC.

The following relation gives the maximum speed of the wind in the mean point of the second part, for the dynamic isolation of these parts

$$\upsilon_{2,MAX} = \frac{\sqrt{\lambda\sin(\theta_1 + 0.04)}}{\cos(\theta_1 + 0.04)},$$ and its mean point will be in normal distance:

$$h_2 = h_1 + h\times\cos(\theta_1 + 0.04).$$

Hence for dynamic isolation the maximum speed of the n[th] part will be:

$$\upsilon_{n,MAX} = \frac{\sqrt{\lambda\sin(\theta_1 + (n-1)\times 0.04)}}{\cos(\theta_1 + (n-1)\times 0.04)} \qquad (9)$$

and their mean point of the n[th] part will be in altitude :

$$h_n = h_{n-1} + h\times\cos(\theta_1 + (n-1)\times 0.04) \qquad (10).$$

For, $\theta_1 + (n-1)\times 0.04 < \frac{\pi}{2}$, if $\theta_1 + (n-1)\times 0.04 \geq \frac{\pi}{2}$ the $\upsilon_{n,max}$ becomes infinite, hence the dynamic isolation can be achieved for any wind speed.

In figure (7) the υ_{MAX} is shown as function of height for the dynamic isolation of the successive parts of FSC, of an initial height H=3000m and internal diameter d=100m, having 15 parts with h=200m each of them. The isolation balloon-rings have height 4m. It is assumed that $\Delta\theta_n\leq0.04$ for every part of FSC.

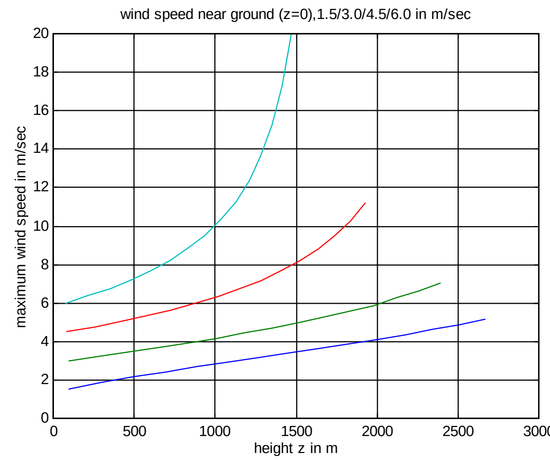

FIGURE 7

In figure (7), four curves are shown corresponding to wind speeds near ground υ_1=1.5 m/sec, 3m/sec, 4.5m/sec and 6m/sec. For a given υ_1 every wind speed in altitude (z), under the corresponding curve, it permits the dynamic isolation of the successive parts of the FSC, under the assumption that $\Delta\theta_n\leq0.04$ for every n.

If local meteorological conditions show that the wind speeds are varied upon the curves of figure (7) and if the total dynamic isolation of successive parts is necessary, the following measures should be taken:

- The FSC to be separated in more than 15 parts
- The height of isolation balloon-rings to be increased

A combination of the previous measures can guarantee, for any local wind altitude alterations, the dynamic isolation of the successive FSC's parts.

4. Conclusions

A new lighter than air structure for very tall solar chimneys was presented.

These solar chimneys can self-float and using its net uplift force by its filling light gas they can stand in an up right position. When external winds are appearing they can deflect avoiding their deformation.

If external winds are variating with altitude, their effect will be a variable deflection angle for FSCs' parts. Choosing appropriately the height of each FSC part and the height of separating balloon ring the differential forces on the FSC parts can be encountered effectively.

The supporting rings, although mainly are used to encounter the operating sub pressure acting on the FSC wall, are also used to encounter the small normal pressure forces on the FSC wall due to the normal component of wind speed on the wall.

References:

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