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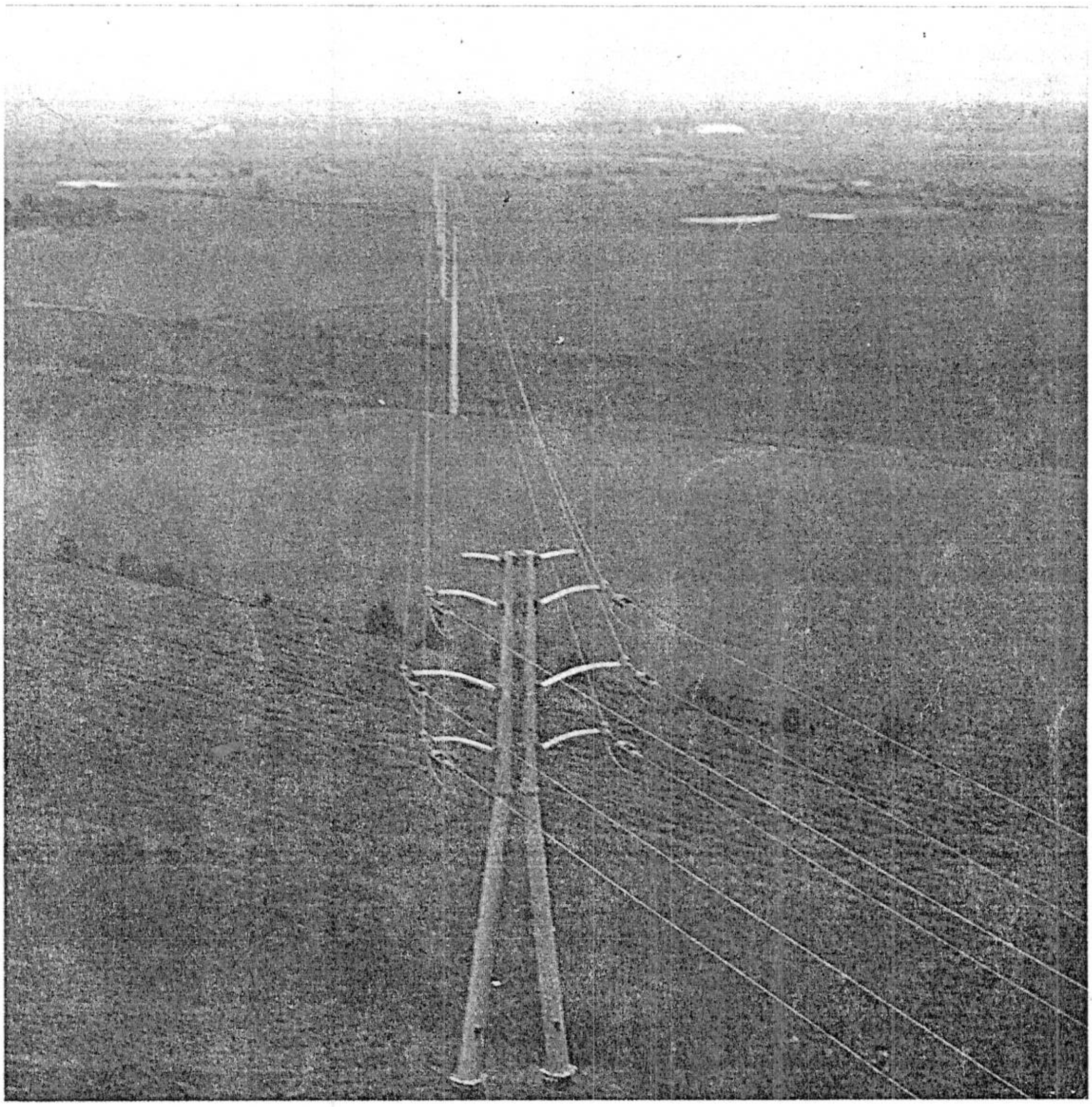

REDUCTION D'ENCOMBREMENT DES LIGNES AERIENNES

COMPACTING OVERHEAD TRANSMISSION LINES

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COMPACTING OVERHEAD TRANSMISSION LINES

RAPPORTS PRESENTES

PAPERS PRESENTED

LENINGRAD

(URSS/*USSR*)

3 - 5 juin/*June* 1991

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Effet sur les résistances mécaniques et les performances des lignes des modifications dues aux réductions d'encombrement, vent, galop des conducteurs, charges dues à la glace, courts-circuits, etc...

Effect on the mechanical strength and performance of lines of the changes related to line compaction. Wind, galloping, ice-loading, short-circuits, etc... are considered

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SECTION 3

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300-01 Technical development of reduced line inductance for bulk power transmission - Y. TAKAGI, M. SUGIHARA, M. ADACHI (Japon/*Japan*)

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200-01

GALLOPING AND COMPACT LINE

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Summary

Galloping could also be a trouble for compact lines.

Compared to classical overhead lines, compact lines present lower sag and reduced clearances. We can deduce that vertical frequencies will be higher (proportional to the inverse of sag square root) and that bundles are to be used for lower voltage level due to corona effect.
In general , critical wind speed (galloping threshold) will be higher than in classical overhead lines and more attention must be devoted to flutter instability in bundle configuration.
Due to reduced clearances, more galloping could induce short-circuit with dramatic damage.
This paper will be focused on flutter galloping on bundle configuration.
We will suggest structural recommendations and propose a new type of anti-galloping device.

Keywords : galloping - anti-galloping device - bundle - compact line.

1. Recommendations for structural design .

1.a Galloping on single and bundle line

It is doubtless that single conductor line galloping is highly related to the torsional stiffness of the conductor, that stiffness increasing proportionally to the fourth power of the conductor diameter. Ice accretion on single conductors strongly depends on span length, conductor diameter and ice density.
Yet , on bundle conductor lines with classical spacer, galloping is more related to structural properties of the bundle and ice accretion is not so dependent on span length (reduced to sub-span length), conductor diameter or ice density.

Vertical instability (Den-Hartog - only with very thin ice *eccentricity*) or torsion-vertical instability (binary flutter - only with ice including significative aerodynamic pitching moment) are the most classical cases for galloping .

1.b Galloping on bundle line

Bundle conductors are very sensitive to flutter galloping because vertical and torsional frequencies are *structurally* close together. This is mainly due to the fact that torsional stiffness of the bundle is very few related to subconductor intrinsic torsional stiffness and very much related to the mechanical tension in the subconductor. Due to spacer connexion (even if it is a rotating clamp spacer) between subconductor, tension causes a very important return torque which ensures the major part of the torsional stiffness.
Moreover it is possible to prove that, when bundle is subject to a torque, it appears a small tension unbalance between subconductors, and that unbalance sensibly (up to 50%) modifies the torsional stiffness of the bundle.
The small tension unbalance is a function of how subconductors are attached to span ends. With appropriate fixation we could easily force a sensible detuning between vertical and torsional frequencies.
As compact lines are generally designed with insulated cross-arms, usually flexible in the longitudinal way, each span could be considered as being a dead-end span with flexible fixation point. This is important for frequency point of view.

1.c Vertical and torsional frequencies

It is possible to establish the following formulas for vertical and torsional pulsation (rad/s) :

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θ = vertical
Θ = torsion

For the antisymmetric modes (two loops for k=2; four loops for k = 4, etc...) :

$$\omega^2_{v,k}=\left(\frac{k\pi}{L_s}\right)^2\frac{T_0}{m} \qquad \text{k even} \qquad \omega^2_{\vartheta,k}=\left(\frac{k\pi}{L_s}\right)^2\frac{1}{m}\left(T_0+\frac{\tau}{r^2}\right) \tag{1}$$

For the symmetric modes (one loop for k=1; three loops for k=3, etc...)

$$\omega_{v,k}=\Omega_v\ f_k(M_v') \qquad \Omega_v^2=\left(\frac{\pi}{L_s}\right)^2\frac{T_0}{m} \tag{2}$$

$$\omega_{\vartheta,k}=\Omega_\vartheta\ f_k(M_\vartheta') \qquad \Omega_\vartheta^2=\left(\frac{\pi}{L_s}\right)^2\frac{1}{m}\left(T_0+\frac{\tau}{r^2}\right) \tag{3}$$

$$M_v'=\frac{b}{\Omega_v^2}=\frac{8a^2K_v}{\pi^2\Omega_v^2 m}L_s \qquad M_\vartheta'=\frac{b}{\Omega_\vartheta^2}=\frac{8a^2K_\vartheta}{\pi^2\Omega_\vartheta^2 m}L_s \tag{4}$$

where the function $f_k(M)$ are presented on the fig. 1 and the variables detailed in annex.

It is to be noticed that symmetric modes could be sensibly shifted by structural action on the factor $K_{v\ or\ \vartheta}$.

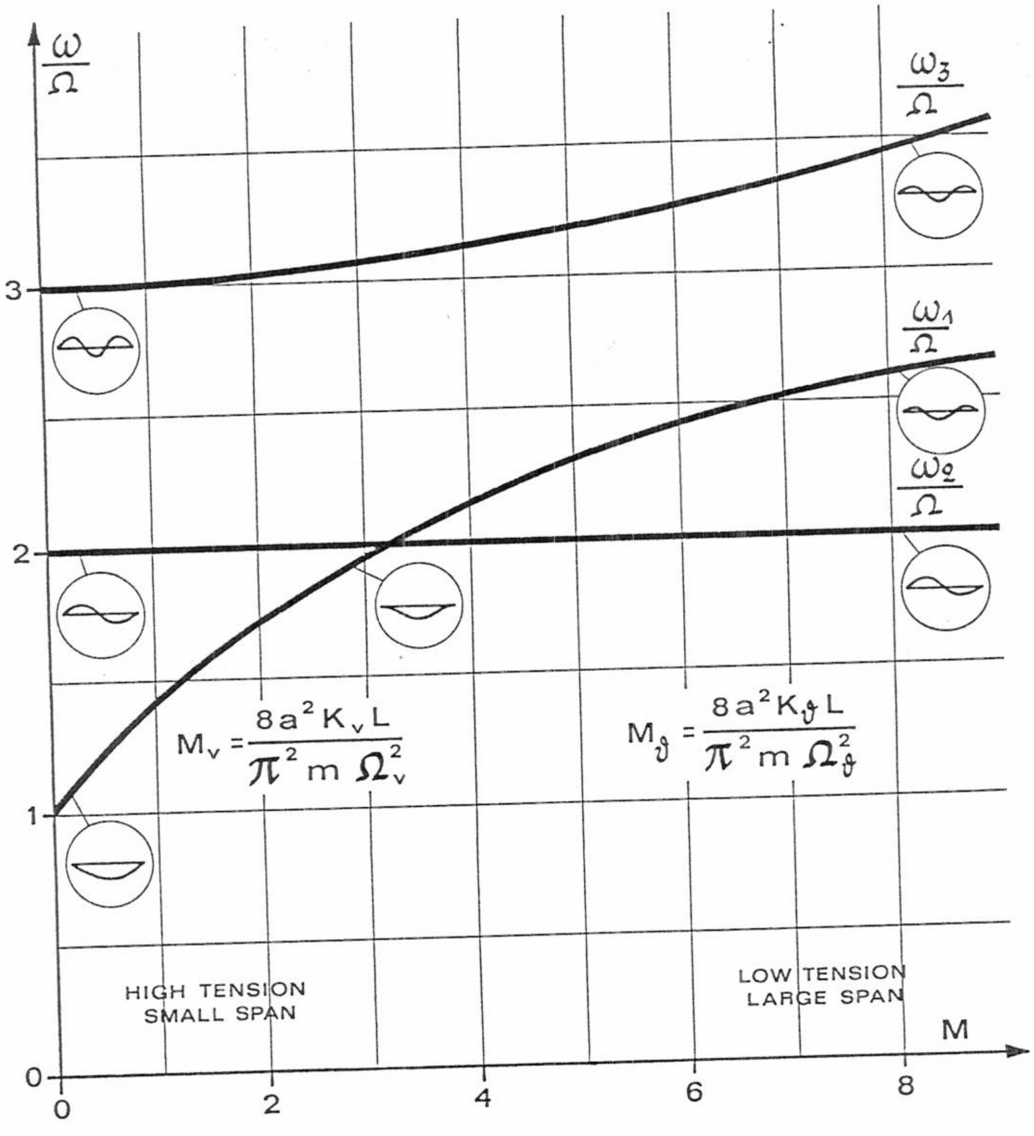

Fig.1 : Influence of structural factor M (M_v for vertical; M_ϑ for torsional motion) on the three first frequencies on a span length L_s in a section line of length L. Thick curves represent the function $f_k(M)$ defined in equations (2) and (3).

$a = \frac{mg}{T}$

For compact line , K_V is very low due to flexibility (= 1/K) of tower cross arm (if K is very low compared to EA/L, then K_V is also very low), so that M_V could be considered close to zero.

$$\frac{1}{K_v} = \frac{1}{K} + \frac{L}{EA} \tag{5}$$

But M_ϑ could certainly not be considered close to zero too. As an example of application this value can be deduced from K_ϑ which is given in the case of a twin bundle :

$$\frac{1}{K_\vartheta} = \frac{1}{\cos^2\sigma}\left(\frac{d^2}{2hT} + \frac{L}{EA}\right) \tag{6}$$

For a vertical bundle $\sigma = \pi/2$ and $K_\vartheta=0$.

For a horizontal bundle $\sigma = 0$ and

$$\frac{1}{K_\vartheta} = \frac{d^2}{2hT} + \frac{L}{EA} \tag{7}$$

Thus vertical configuration has to be proscribed.

1.d Recommendations

To detune vertical and torsional frequencies as much as possible, we could recommend for compact line :

a) to ensure very flexible longitudinal stiffness of insulated cross arm to minimize vertical frequency (see f.e. report [1])

b) to ensure maximal torsional stiffness by appropriate yoke plate design (f.e. longitudinal dimension of the yoke (h in the formula) must be close to twice subconductor separation (d in the formula)) and to use spacers with eccentric weight

2. A new anti-galloping device

As suggested in other publication [2], we developped with a U.K. manufacturer an antigalloping device based on the combination of both principles :

- high torsional damping
- appropriate detuning effect

One of the biggest problem to solve was to find out appropriate damping material and general shape for very low frequency oscillation. The final design will be shown at the symposium.

This device has been tested by Laborelec (Belgium) on a short span (about 40 m) and two of them have been putted on a full scale experimental line in the Ardennes (span length about 300 m, equipped with horizontal twin 2x620 AMS). It is a dead-end span and the devices have been installed for the winter 90-91. Results, if any will be presented during the symposium.

3. Simulation results

There are many papers on galloping but only a very few part gives access to practical datas and experimental results.

One of the most interesting has been published in CIGRE 1974 and datas used in our simulation have been taken from experiments on Kasatori-Yama line (Japan) [3]

We early published detailed simulation on tension variation both in cable and suspension insulators in CIGRE 1990 [4]. We will now present amplitude results obtained by simulation on quad 950 ACSR bundle - over a section line of two spans /312m/319m/ - with naturally iced conductors /0.6 kg/m, ice density 0.2/ - with 0.5m separation between subconductors - tension was 18600 daN per phase (sag about 8 meters) fixed to anchoring tower by two insulators and to suspension tower by one insulator. Intrinsic torsional stiffness of each subconductor was about 760 Nm2. We have supposed that torsional damping was about 6% and vertical one about 0.5% of critical damping.

We have computed equi-amplitude (peak-to-peak) curves depending on wind speed and ice accretion angle. Eccentricity was adapted to fulfill observed ice weight with given density. Corresponding aerodynamic curves was taken from litterature.

3.1 Observations from obtained results

Ice accretion angle for galloping conditions :

We must notice that this accretion angle is not the same at mid-span compared to end of the spans. That is because aerodynamic pitching moment give an equilibrium position at mid-span different from the end of the spans where subconductors are torsionally fixed in the clamps. Of course the angle shift from one end to mid-span is increasing with the wind speed.

We decided to put in abscissa the accretion angle at the end of the span. The dotted line on fig. 2 gives access to ice position at mid-span for the particular case of 40° upwards to the wind. For small wind there is no angular shift, but at 15 m/s the shift is about 25° for the quad 950 ACSR.

Galloping occurs for ice accretion close to -40 to -60° at mid-span (corresponding to -10° to -50° at anchoring level)

If we follow the dotted line, means that we observed the behaviour of the line for increasing wind at constant accretion angle , there is no galloping for wind lower than 5m/s or bigger than 15 m/s. The peak-to-peak amplitude grows until 8 meters for wind close to 12 m/s

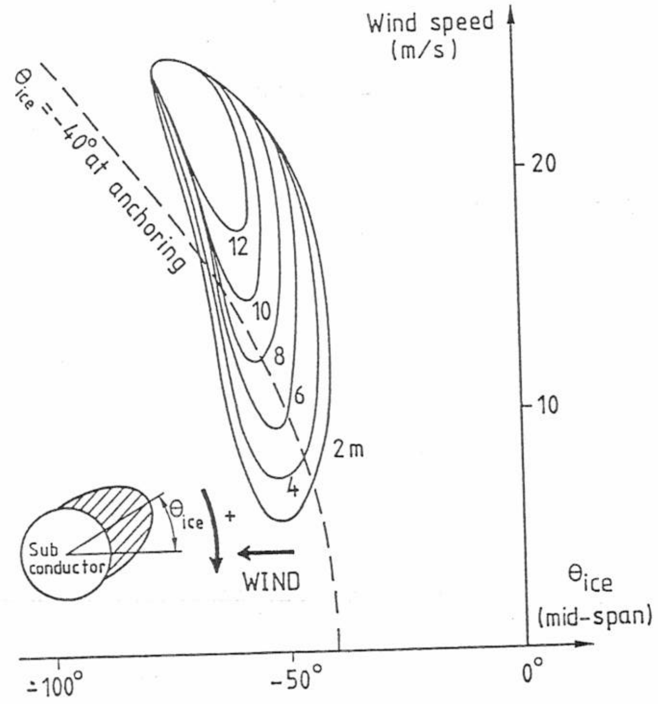

Fig. 2 : Kasatori-Yama line expertise. Quad bundle 950 ACSR with naturally iced conductors (0.6 kg/m, ice density 0.2). Equi-amplitude (peak-to-peak) for flutter galloping expressed as function of wind speed vs ice accretion orientation at mid-span. (-50° means 50° upwards wind)

3.2 Parameters variations effects

If we simulate similar curves as explained in 3.1 for different ice eccentricity, torsional damping and conductor separation, we may have a sensibility analysis.
In order to present it in a more synthetic vue , we have computed the probability of galloping supposing that equal probability exist to have wind between 5 and 30 m/s and ice accretion between 0° and -90° . The corresponding probability of galloping to have a given amplitude has been deduced from area of equi-amplitude. see fig.3

a. the decrease of subconductor separation (from 0.5 to 0.4 m) increase the probability of galloping and slightly lowered the maximum amplitude.
b. The increase of torsional damping from 6 to 10% have a very beneficial effect for reducing both probability and maximum amplitude.
c. A thicker ice (ε from 0.33 to 1.5, meaning ice thickness from 1/6 to 3/4 of subconductor diameter) will sensibly increase the probability but has limited effect on maximum amplitude.

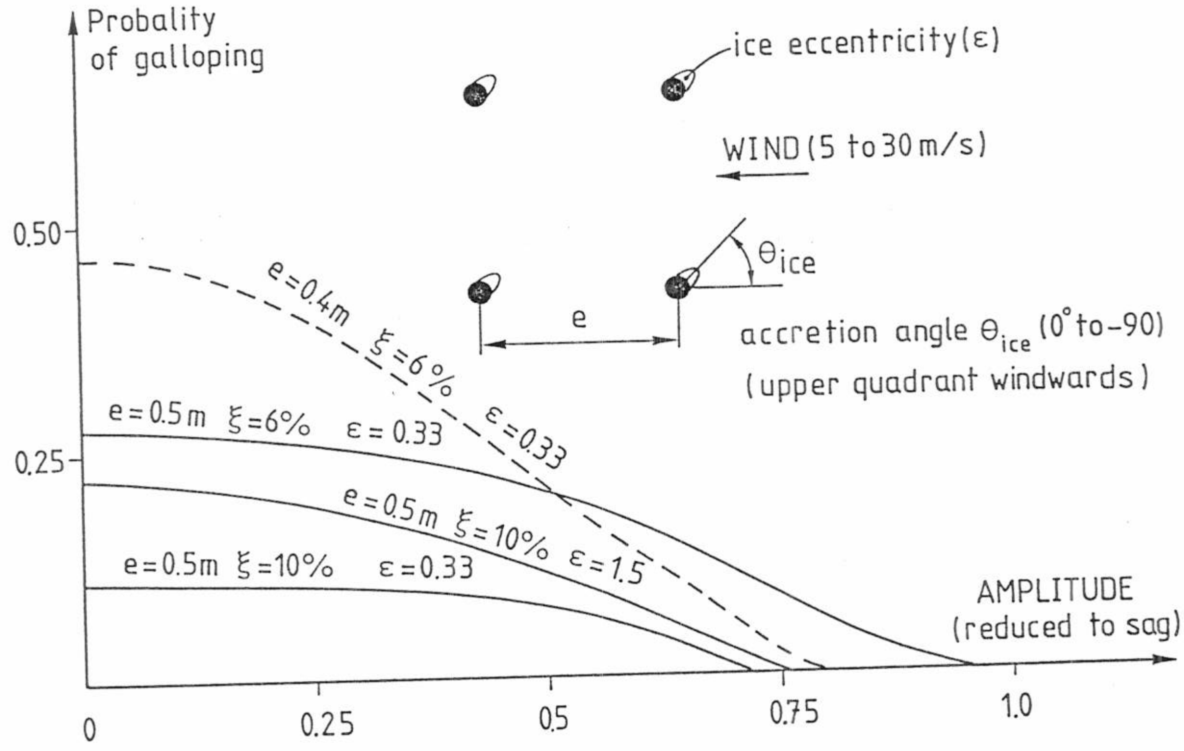

Fig.3 : Kasatori-Yama line expertise. Influence of some parameters variation on the probability of galloping for wind between 5 and 30 m/s and ice accretion in the upwards wind quadrant. - e - is subconductor separation, - ξ - the torsional damping and - ε - the ice eccentricity expressed as the ratio thickness/ subconductor radius.

4. Conclusions

The use of compact line will probably favour more galloping because of wider use to bundle line due to corona effect. Fixation to tower through insulated cross-arm with free longitudinal movement could increase the danger of collapsing between vertical and torsional frequencies if specific arrangement for subconductors fixation are not taken into account.
We have proposed some structural adaptation.
Appropriate tools for galloping expertise are now available.
We suggest to use a new type of anti-galloping device to avoid any trouble.

Acknowledgement

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Notations

a	inverse of the catenary parameter (m^{-1}) $= mg/T$
τ	intrinsic torsional stiffness of one phase ($N\,m^2$)
m	mass of one phase p.u. length (kg/m)
E	Young modulus (N/m^2)
A	cross section *of one phase* (m^2)
K	anchoring stiffness off both end towers in serie (N/m)
K_v	equivalent stiffness for vertical motion (N/m)
K_ϑ	equivalent stiffness for torsional motion (N/m)
d	subconductors spacing (m)
r	radius of the bundle (m)
N_s	number of spans in a line section
n	number of subconductors in a bundle
L	span length of the whole section (m)
L_s	span length of span s (m)
M_v	structural dimensionless parameter for vertical motion
M_ϑ	structural dimensionless parameter for torsional motion
Ω_v	base pulsation for vertical motion (rad/s)
Ω_ϑ	base pulsation for torsional motion (rad/s)
$\omega_{v,k}$	k^{th} pulsation of the vertical mode (rad/s)
$\omega_{\vartheta,k}$	k^{th} pulsation of the torsional mode (rad/s)
T	instantaneous mechanical tension *in one phase* (N) (T_o initial static value)

Résumé

Le galop des conducteurs est un problème qui peut exister également dans les lignes compactes. Suite à la réduction des distances d'isolement, l'utilisation des conducteurs en faisceau sera souvent un impératif. Ce type d'armement est particulièrement sensible au galop dans certaines conditions qui pourraient fort bien être réunies dans certaines lignes compactes. Nous proposons des adaptations structurales, notamment quant à la fixation des sous-conducteurs sur leurs ancrages. Un nouveau dispositif anti-galop pour lignes en faisceau est également présenté. Enfin on fait l'expertise d'une ligne japonaise pour mettre en évidence les possibilités de prédétermination des amplitudes. Une étude paramétrique confirme l'intérêt du dispositif proposé qui se base sur l'augmentation de l'amortissement en torsion du faisceau.