Full-Scale Tests of Torsional Damper and Detuner (TDD) Antigalloping Device

Jean-Louis Lilien, *Member, IEEE*, and Alexandre A. Vinogradov

***Abstract*—A new antigalloping device for overhead lines with bundle conductors was introduced ten years ago, after laboratory tests and observations on actual 400-kV lines. A systematic full-scale test was performed in Kazakhstan in order to better evaluate torsional damper and detuner (TDD) efficiency. This report details the test station and the results obtained over a several month period of testing and measurement. The tests were carried out thanks to the mutual efforts of the ESSP and the Kazakh Power Research Institute (KazNIIE) at the field tests stand located in Chokpar.**

***Index Terms*—Measurement, power transmission lines, test facilities, vibration control.**

I. Introduction

GALLOPING, or the large vibrations of overhead transmission lines due to wind action and the presence of ice deposits on the conductors, is a frequent problem in badly situated lines [1], [3], [6]. Galloping occurrences strongly depend on a combination of wind speed, wind direction and ice shapes. Systematic tests can only be envisaged using artificial ice shapes, similar to those observed in the field [5]. This is what was done in the tests. Structural data are also important and can be partially adjusted by appropriate tension in the conductors and bundle geometry. Suspension spans have basic frequencies lower than anchoring spans, which make them more susceptible to galloping with lower wind speeds in their single loop mode.

II. Test Facility

The three-span experimental stand located in an open terrain site (Southwest Kazakhstan) has been equipped especially for experiments on conductor galloping (Figs. 1–4). The site is in the Jambul region, not far from the Chokpar railway station, close to the Kurdai upland—a zone famous for strong winds. Compass-card was defined during the period from 02.02.98 to 27.05.98, shown in Fig. 3. Both average and maximum wind speeds for 16 directions are shown on the diagram. On Fig. 4, one sees that the experimental stand is oriented mainly perpendicularly to prevailing eastern and western winds. The bundled conductor (type 2 $\times$ ACSR-400/51) is mounted in the spans and two dead-end assemblies and two suspension assemblies used in the fixing points. The middle span's length is 292 m, and the lengths of the extreme (anchor) spans are 78 and 84 m. The stand's profile appears in Fig. 2. Mechanical data of the AC-400/51 conductor is given in Table I.

Fig. 1. Southern suspension tower B; Northern (C) is similar.

The distance between horizontally located conductors in the bundle is 400 mm. Five rigid spacers were installed along the length of the central span at approximately equal lengths. To make the suspension units more flexible in longitudinal and lateral directions, ropes are used to fix them at the chosen height (Fig. 1). Manual winches which can be seen to the left of both towers are used to turn the bundle through the ropes and wheels at an angle $\pm 15°$ (one turn of a winch handle gives a bundle rotation of 5°).

Deviation in anchor span lengths is defined by local relief. In spite of the different lengths of middle and extreme spans, the experimental stand is close to the three-span fragment of a transmission line with approximately equal span lengths. For this reason, conductors in the extreme spans are equipped with additional weights, uniformly distributed over their lengths, to provide equal inclination angles of the conductors at the both sides of the intermediate suspension points.

Airfoils with shapes similar to ice deposits observed in real weather conditions were installed on both conductors (Figs. 5–7). Two airfoils were used (the second one, for the period 22.04.98–05.05.98). Weights and geometrical parameters of the airfoils are also shown in Fig. 5. The weights of

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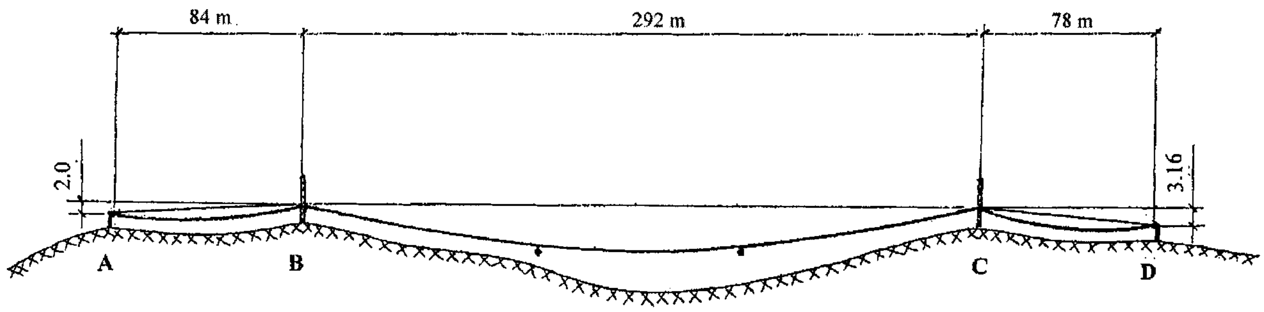

Fig. 2. Side-view of the stand (horizontal and vertical scales are different). Points of the torsional damper and detuner's (TDD) installation are given as sketches.

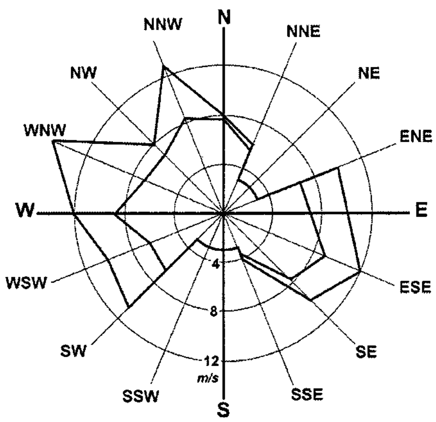

Fig. 3. (Upper part): Compass-card with average and max wind speed information.

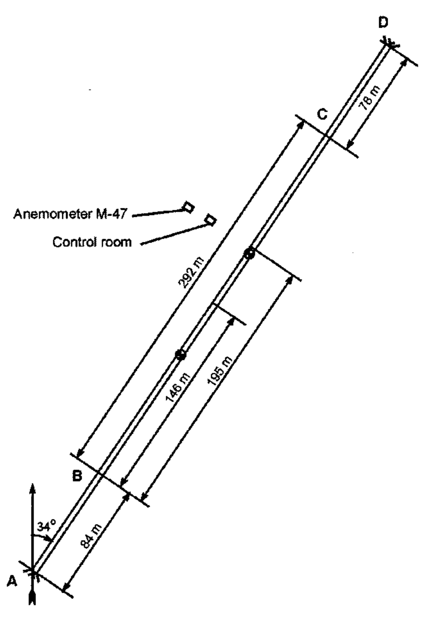

Fig. 4. (Lower part): Plan of the experimental stand: A and D—anchor towers, B and C—suspension ones.

both designs were determined by weighing ten pieces. As eastern winds are considered more stable and more frequent, the airfoils were mounted toward the East in all cases.

Major variations of attack angles relative to wind direction were carried out by means of reinstallation of the airfoils along the whole length of the middle span. The following positions were chosen for experiments: $-90°$; $-45°$; $0°$. In the case of reverse winds, the corresponding values for the attack angles were $+90°$; $+135°$; $+180°$ [in accordance with the attack angle reading, Fig. 5(c)].

TABLE I
ACSR 451 CONDUCTOR USED IN OUR TESTS

section *mm^2*	Diameter *mm*	UTS *daN*	Mass *kg/m*
394.0 (Al) 51.1 (Steel)	27.5	11540	1.49

After initial installation, the airfoil position in the middle part of test span was corrected. It proved necessary to compensate for angular error because of conductor stiffness.

With the help of suspension wheel rotation, additional deviation of the attack angles was obtained. Variations in initial conductor tension were carried out using turn-buckles fastened to the anchor towers.

III. MEASURED VALUES

We systematically measured the following:

– max peak-to-peak galloping amplitude (2 A in meters) (Fig. 8);
– some time evolution of galloping (Fig. 9);
– peak-to-peak torsional amplitude (2φ in °) (Fig. 10);
– some time evolution of torsion (Fig. 9);
– one subconductor tension (daN) (initial and time evolution) (Fig. 11);
– wind velocity (m/s) at the height of conductor.

All these measurements have a precision range of approximately 8%.

The twisting angles of bundled conductors were also read visually in antinode points using scales (Fig. 10), which were installed at mid-span, at one-quarter of span length and one-sixth of span length.

Wind speed was measured using a stationary anemometer or a hand-born one. Static tension in conductors was measured visually with a mechanical dynamometer (Fig. 11); tension variations in galloping process were recorded with the help of a load cell.

IV. TESTS WITHOUT TDDS

A. *Without Torsional Damper and Detuners (TDDs)*

The first stage of tests was devoted to measuring test span loop frequencies (Table II) and to observing galloping of the line

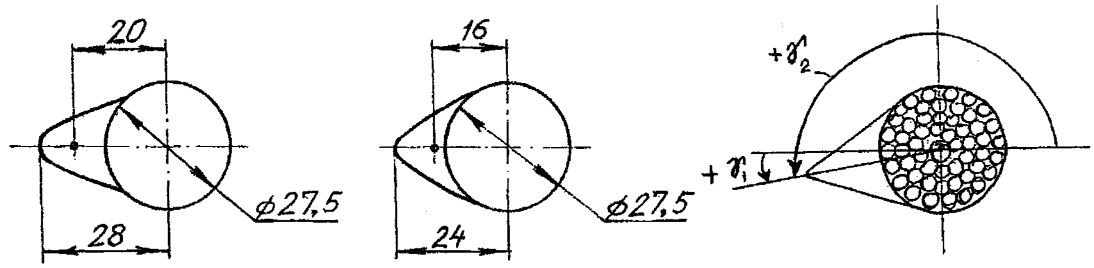

Fig. 5. Geometry of the airfoils of (a) ESSP and of (b) KazNIIE mounted on the conductor. Center of gravity location estimate for the airfoils is given. (c) Angle of attack definition.

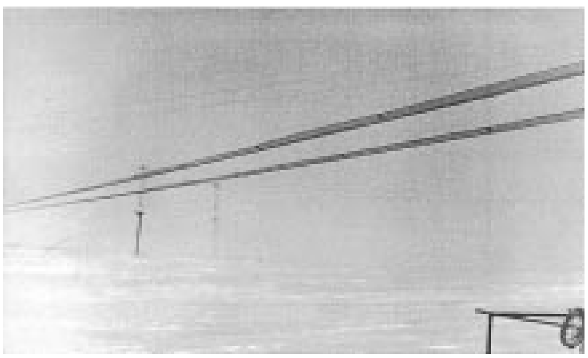

Fig. 6. Airfoils of ESSP fixed on the bundled conductors.

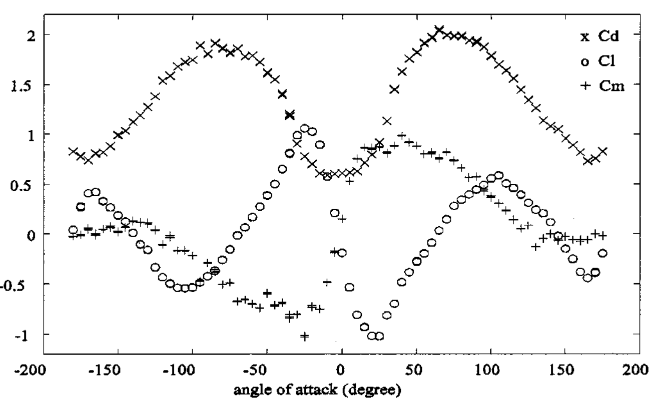

Fig. 7. Quasisteady measured aerodynamic coefficients of drag (Cd), lift (Cl), and moment (Cm) measured in wind tunnel on similar ice shapes.

Fig. 8. Manual peak-to-peak amplitude meter.

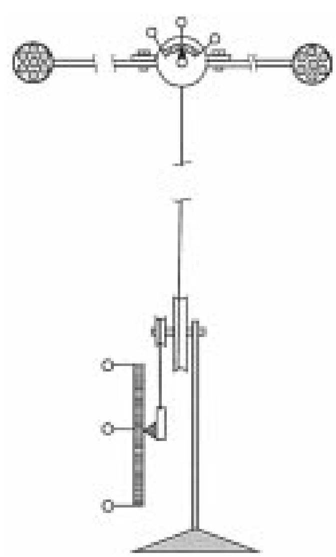

Fig. 9. Sketch of the linear and angular potentiometric amplitude meters.

for different wind speeds, different tensions in the conductor and different airfoil positions. This was done continuously for four months. Many oscillogramms and tests results were recorded as wind speed in that region is especially frequent. (The authors of this report were there for two days in May 1998; in that period wind speed was higher than 10 m/s continuously, day and night.)

Representation of Galloping Observation Results: A number of observations of bundle galloping (or its absence), are represented below as follows.

All the data describing stability/instability patterns of the bundle during in-wind conditions, are put together on polar diagrams Fig. 12 for one loop. Amplitudes are given in relative units (r.u.), i.e., values of double amplitude 2 A were divided by sag value f_0 at a given tension.

Dependencies of galloping amplitudes versus perpendicular components of wind speed are shown on Fig. 13 for one loop as well.

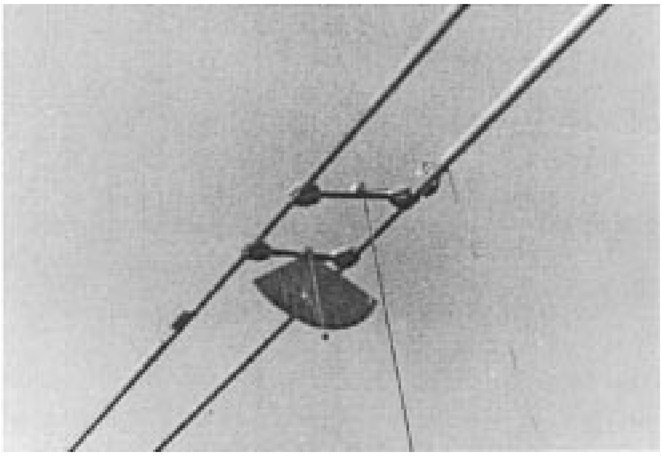

Fig. 10. Scale to visually measure rotation angle and angular potentiometer.

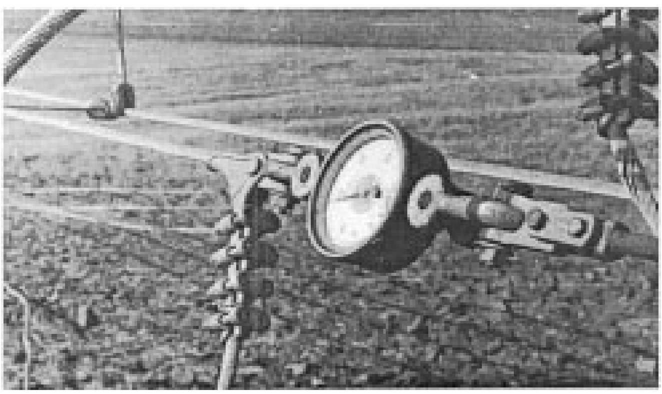

Fig. 11. Dynamometer for static tension evolution.

TABLE II
NATURAL FREQUENCIES ON THE BUNDLE

Excitation point	Number of loops	Tension T_0 = 2650 daN			Amplitudes of oscillation approximately
		Vertical oscillat.	Torsion oscillat.	Horiz. oscillat.	
L / 2	1	0.33	0.36	0.19	Initial amplitude of vert./horiz. oscill. (peak – peak) 0.5 m
		0.34		[1])	Initial amplitude of vert. oscill. (peak – peak) 2.0 m
L / 4	2	0.45	0.44	0.50	Initial amplitude of vert./horiz. oscill. (peak – peak) 0.5 m
		0.46		[1])	Initial amplitude of vert. oscill. (peak – peak) 1.5 m
L / 2	3	0.70	0.70	0.64	Initial amplitude of vert./horiz. oscill. (peak – peak) 0.5 m
		0.72		[1])	Initial amplitude of vert. oscill. (peak – peak) 1.5 m

Notes: [1]) Measurements were not carried out
Data on natural frequencies *f* of the bundle in *Hz*

Amplitudes of galloping in r.u. turned out to be practically independent of tension value T_0, but the graph does not appear here.

B. TDD Tests for Galloping Control

The second stage of the tests was devoted to determining the capability of TDDs to protect against galloping. Oscillographic recording was also carried out in this time period.

Technology for the tests had been chosen assuming that the only one test span was available. During this stage, when stable weather conditions with high winds occurred, airfoils were installed at points most favorable for oscillation position

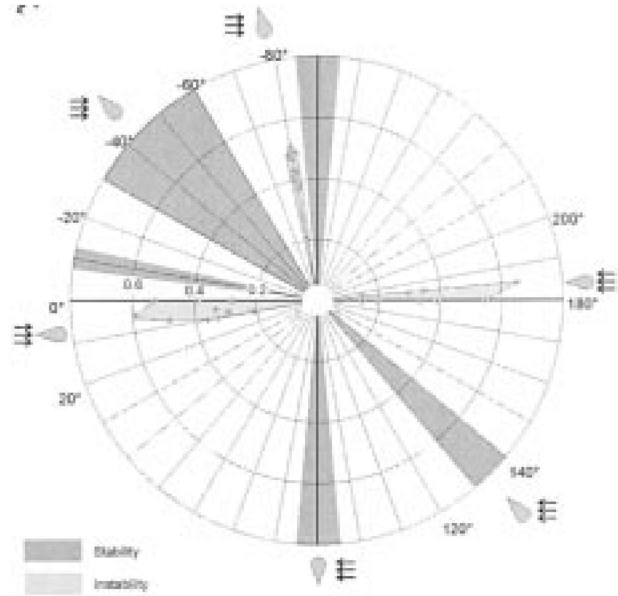

Fig. 12. Results of galloping observations at the Chokpar experimental stand. Stability/instability zones of twin conductor bundles, with respect to the airfoils attack angle (their positions in wind flow are given on nearby pictograms). The rule for attack angle reading is in Fig. 5. Amplitudes of galloping are given in relative units (2 A/f_0). One-loop data. Similar curves exist for two and three loops.

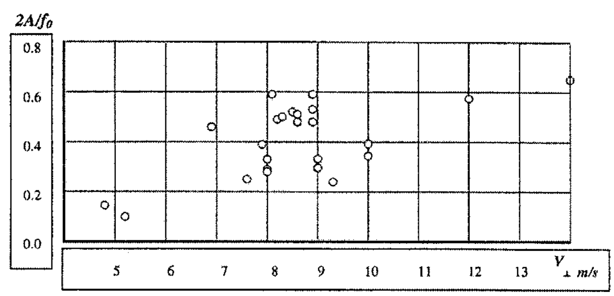

Fig. 13. Dependence of galloping amplitude versus perpendicular wind component. One-loop data in r.u.

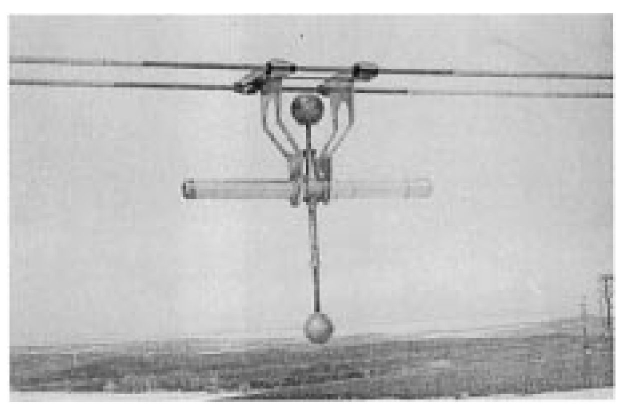

Fig. 14. TDD device installed on the test span.

and galloping amplitude and twisting angles were measured (during a period not less than 30 min). Then, galloping was blocked with suspension wheel rotation at both suspension towers (using the manually-operated winches) in a position excluding oscillations.

TABLE III
GALLOPING OBSERVATIONS WITH AND WITHOUT TDD

Wind direction	Tension T_0,[daN]	α, [°]	Parameters of galloping: Before TDDs installation V_{wind} [m/s]	$2A_{free}$ [m]	2φ [°]	After TDDs installation V_{wind} [m/s]	$2A_{TDD}$ [m]	2φ [°]	Period of test	After TDDs removal V_{wind} [m/s]	$2A_{free}$ [m]	2φ [°]	TDDs efficiency η, [%]
E, 60⁰	3250	+10	7 - 10	· 1.20	15÷30	6 – 10*	max 0.09**	5 - 15	12 hrs	6 - 12	1.18	20÷40	92
						Osc. 1**, Osc. 2							
E, 60⁰	3200	+10	8 - 10	~ 1.9	25÷30	7-9	~ 0.2	5-20	1 hour	9-11	2.10	25÷40	90
ESE,80⁰	3050	–80	6 - 9	2.4	30–40	7-10*	~ 0.3 #)	10-15	14 hrs	6-8	2.15	25÷40	86
			Osc. 3										
ESE,90⁰	2700	–80	6 – 9	3.1	40–50	6-8	max 0.36**	10-15	1 hour	7-9	3.50	40÷50	88
						Osc. 8, Osc. 9, Osc. 10							
ESE,90⁰	2700	–80	5-8	1.6	20–30	5-7	~ 0.15	5 - 10	0.5 hr	5-7	1.2	40÷50	90

Notes: *) Constant observation of the bundle behaviour during overnight was not carried out; pen recording was made at 01^{10} - 01^{30} (21.05.98).
**) Oscillographic records data exist but are not reproduced here.
#) Observation was carried out in the beginning and by the end of the test period.

Five tests were performed with TDDs at different tensions (from 2700 daN up to 3600 daN) for the worst airfoil positions (see stage 1), including several other positions.

Two TDDs were installed (one at 35% of span length and the other at 65% of the span from tower B) TDD characteristics were chosen to avoid one, two and three loops in a range up to 15 m/s [4] (Fig. 14).

Previous airfoil attack angle was recreated afterwards through reverse rotation of the winches. The bundle behavior was observed and registered once again during a time period of not less than 30 min. The TDDs were then dismounted (this procedure took approximately 0.5 h), and bundle galloping immediately occurred.

The galloping parameters were registered once again. Thus, each test lasted not less than 4.5–5 h. Identical tests were carried out five times (in two tests TDDs were left installed and exposed to wind overnight). The first two tests were carried out when airfoils had an attack angle $+10°$, the others had an attack angle of $-80°$. The typical behavior of the bundle, with the TDDs installed and wind 6–10 m/s blowing, can be explained as rather small chaotic displacements of both conductors in a vertical direction. This produced sporadic outbreaks of small amplitude oscillations of probably one-loop frequency; the phenomenon occurred from time to time, but disappeared quickly. The results of TDDs tests are summarized in Table III. The last column shows estimations of TDDs efficiency η in galloping suppression as

$$\eta = (2A_{\text{free}} - 2A_{\text{TDD}})/2A_{\text{free}} \cdot 100\%.$$

It was decided to obtain additional assurance of TDDs capacity to stop galloping in the following experiment. An attempt was made to initiate galloping during in-wind conditions, with the TDDs installed, by additional excitation of oscillations. This was done by hand-twisting of the conductors at a quarter point of the span. Oscillations of small amplitude, most likely of two-loop frequency, appeared for a short period just after excitation and then quickly disappeared.

V. CONCLUSIONS

Test results at the Chokpar experimental station determine the efficiency of TDD devices can be summarized as follows.

1) *Stand preparation*: The three-span test stand for galloping observations was equipped with twin conductor bundles and a set of measuring devices. Airfoils similar to real ice deposits were prepared and installed on the conductors.
2) *Galloping observations*: The bundle galloping inception for a range of attack angles was statistically inspected for East/West winds up to 13–15 m/s. In every case when winds occurred blowing higher than 6–8 m/s (components perpendicular to the span) and when the airfoils were in an instability zone, galloping was reliably initiated.
3) *Galloping data representation*: The data obtained (more than 100 cases) were processed and represented in tables, polar diagrams and regression curves.
4) *TDD tests*: The tests were carried out during steady winds conditions and airfoils installed at the most favorable attack angles for galloping. The tests basically consisted in the comparison of bundle oscillations without TDDs, just prior their installation, and after TDD installation at prescribed points, other variables being equal. Important decreases in galloping were observed in all five tests undertaken. And vice versa, that is a re-occurrence of galloping of approximately equal amplitude took place after the removal of the TDDs in every case. TDD efficiency in protection against galloping was 86–90%.

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