INTERNATIONAL CONFERENCE "ENERGY OF MOLDOVA – 2012. REGIONAL ASPECTS OF DEVELOPMENT"
October 4-6, 2012 - Chisinau, Republic of Moldova

HIGHLY EFFICIENT ANTI-GALLOPING DEVICE TDD FOR TRANSMISSION LINES WITH BUNDLED CONDUCTORS – DEVELOPMENT, TESTS, DESIGN VERSIONS

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Abstract – *Conductors-components of the bundled phase of overhead extra high voltage lines (EHV overhead lines), at the onset of severe weather conditions may be exposed to galloping. Antigalloping dampers are applied for their protection. The authors developed Antigalloping damper for bundled conductors, known as TDD (Torsional Damper and Detuner), which is considered the most effective way to protect the conductors of EHV overhead lines. When selecting a damper concept and its projecting, several designs were created and tested on a number of important parameters of the device. The advantages and differences are shown between TDD device from its nearest counterpart – antigalloping pendulum detuner.*
Keywords – *Overhead Line, Galloping, Anti-Gallop Protection*

AMORTIZATOR DE BALANSĂRI TDD DE EFICIENŢĂ ÎNALTĂ PENTRU LINIILE DE TRANSPORT A ENERGIEI ELECTRICE CU CONDUCTOARE SEPARATE – ELABORARE, ÎNCERCARE, VARIANTE DE REALIZARE

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Rezumat - *Conductoarele ce formează fazele cu fire separate ale LEA de transmisie de tensiune foarte înaltă (LEA TFÎ) la apariţia condiţiilor atmosferice nefavorabile pot fi supuse efectului de balansare. Pentru protecţia acestora se utilizează amortizatoare. Autorii au elaborat amortizator al balansărilor fazelor cu conductoare separate, ce a fost numit TDD (*Torsional Damper and *Detuner, adică amortizator şi deformator al oscilaţiilor de rotire), care se consideră eficient pentru protecţia conductoarelor* liniilor *cu faze dispersate. La selectarea parametrilor amortizorului şi construirea acestuia au fost realizate şi încercate după un şir de parametri importanţi câteva construcţii ale instalaţiei. Sunt arătate avantajele şi deosebirile amortizorului TDD faţă de analogul său apropiat – amortizor de oscilaţii tip pendul.*
Cuvinte cheie - *linie aeriană, balansare, amortizor de balansare*

ВЫСОКОЭФФЕКТИВНЫЙ АНТИПЛЯСОЧНЫЙ ГАСИТЕЛЬ TDD ДЛЯ ЛИНИЙ ЭЛЕКТРОПЕРЕДАЧИ С РАСЩЕПЛЕННЫМИ ПРОВОДАМИ - РАЗРАБОТКА, ИСПЫТАНИЯ, ВАРИАНТЫ КОНСТРУКЦИИ

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Реферат – *Провода-составляющие расщепленной фазы воздушных ЛЭП сверхвысокого напряжения (ВЛ СВН), при возникновении неблагоприятных атмосферных условий могут подвергаться воздействию пляски. Для их защиты применяются гасители пляски. Авторами разработан гаситель пляски расщепленных фаз, получивший название TDD (*Torsional Damper and Detuner, *т.е. Гаситель и Расстраиватель крутильных колебаний), который считается наиболее эффективным для защиты проводов линий с расщепленными фазами.. При выборе параметров гасителя и его конструировании были созданы и испытаны по ряду важнейших параметров несколько конструкций устройства. Показаны преимущества и отличия гасителя TDD от его ближайшего аналога – маятникового гасителя пляски.*
Ключевые слова – *Воздушная линия, Пляска, Гасители пляски*

1. OUTLOOK

Reliability of power supply is a critical factor in ensuring the safety of modern industrial society. In most countries, outages result in the imposition of fines on the Power delivery Companies.

Overhead Transmission line (OHTL) conductors constantly undergo to climatic impacts, especially severe as the air temperature approaches to the zero mark. This weather gives born unpredictable combinations of wet snow or rime or ice being deposited on conductors with the wind usually occurring immediately or afterwards. As a result, dangerous low frequency and high-amplitude vibration of OHTL conductors appears. It is known as galloping. Galloping has mostly the form of standing waves associated with the OHTL spans. They can produce and do bring about different problems and failures to conductors, hardware, cross-arms, sometime even to Towers, due to high mechanical overloads occurring at galloping. Correspondingly, additional costs may be associated with the repair works, these works may cost as little as a few thousand dollars when the minor repair is to be performed in an easy access and as much as millions in a case, say, of the Tower major wreckage or the like.

2. BUNDLED CONDUCTORS GALLOPING SHORT SURVEY

Main subject of this paper is to expose to the Reader advantages (and few drawbacks too) of the novel weapon for our efforts to overcome galloping on Transmission Lines. Its action can be commented on without cumbersome travels into theory of Galloping which is easy to be found elsewhere [1,2].

Galloping is known to occur in the cases when:

• ice deposition on the conductors takes place so as they become aerodynamically unstable;

• ice deposition on the conductors is followed by a high or moderate crosswind blowing steadily along the Line route.

To the outside observer, galloping is a harmonic or pseudo-harmonic movement of the conductor or conductor bundle, with the vibration nodes localized near the supporting points – Towers. As a demonstration pattern, typical forms and frequencies of conductors'` vibration at galloping (the first four frequencies) are exposed in Fig. 1 (calculation was performed at no ice, no wind conditions).

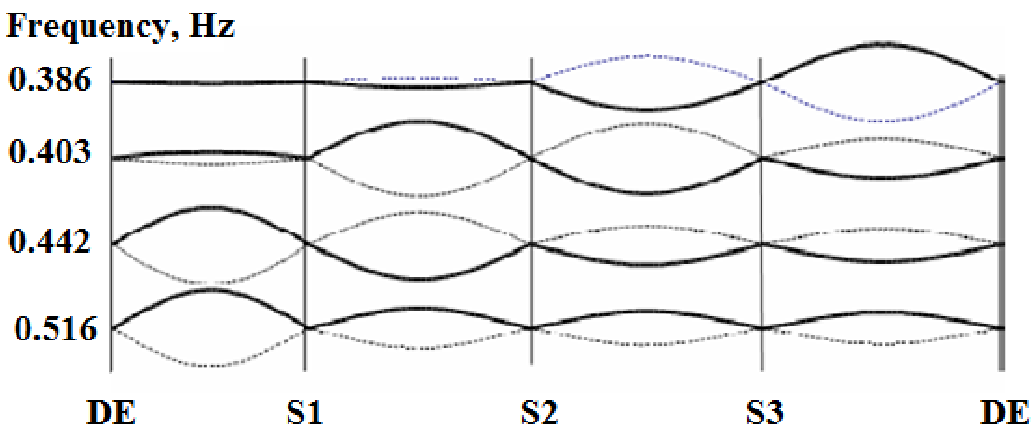

Fig. 1. Typical form of galloping: one-loop mode shape (4-span section, lengths of spans are unequal) [1]

Practice of exploitation of Power Lines with single conductors as compared to bundled designs, demonstrates that bundled conductors undergo more often and severe galloping than the ones with single conductors. The main reason of this divergence is that the only slight discrepancy exists between torsional and vertical frequencies for the bundled conductors, by nature of the forces restoring the bundle equilibrium. Calculations supported with direct video registrations reveal that the bundle while galloping travels as a whole along an elliptical orbit and swings synchronously.

If propagation of the bundle along this orbit is being traced attentively (on video record for example), one can observe that its angular position changes constantly as it is seen in Fig. 2 (this orbit is obtained with the help of calculations [3]; this form is also supported by observers and videorecords).

It is obvious that galloping, as a result of random combinations of the two different actions of Nature (ice forms, wind parameters), becomes a doubly stochastic process. We will certainly fail to control galloping if we would have tried to tune our Antigalloping protection to different cases of galloping itself. Favorably, mechical parameters of the system being under action of galloping, can be easily described and foreseen. As the Power Line spans have usually constant tension and uniform conductors along its route, the main parameter responsible what frequencies are to be expected within a section, is the spanlengths combination. Generally, these frequencies will be slightly shifted with presence both of ice and wind (the heavier ice sleet and higher wind, the more this shift).

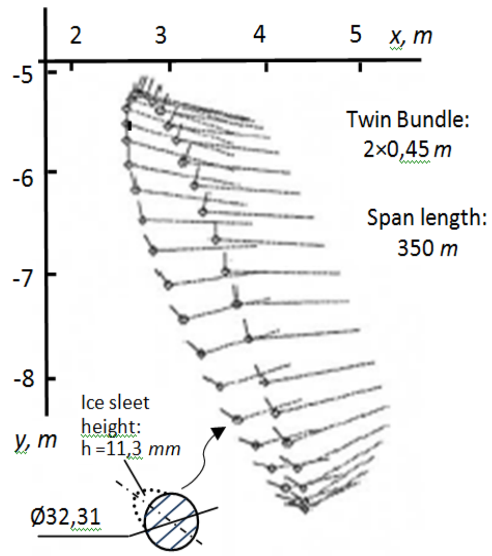

Fig. 2. Calculation results, view of the twin bundle orbit (mid-span) while galloping: short lines – ice sleet tip position on the bundled conductors, lengthy ones –AD forces direction. Time intervals between points 0,1 s.

Aerodynamic forces at Galloping born and kept high with the ice sleet formatted and fixed on the conductors' surfaces, try to increase the orbit in dimensions, as it is seen from Fig. 2. Aerodynamic damping, mechanical self-damping of the structure provides the vibration power dissipation and prevents from amplitudes growth.

3. IDEA OF THE TORSIONAL DAMPER & DETUNER (TDD) AND THE FIRST DESIGN WORKED OUT AT LIEGE UNIVERSITY

3.1 Introduction. Why TDD?

Development of the idea laid into a conceptionally new Anti-galloping device, started in the **University of Liege** about two decades ago [4]. It was further supported with the design development, calculations and tests in the frames of the European **INTAS grant ID: 03-51-3736** (2003-2007). Its design is clear from Fig. 3, overall view can be seen in Fig. 4. The structure of the device and its parameters are especifically intended to suppress high-amplitude vibrations of the Power Line bundled conductors, arising while galloping.

The new Anti-galloping device acquired its own term: **Torsional Damper & Detuner** (or shortly **TDD**). The name underlines that the two effects are used in combination in the apparatus:

• quite a decent detuning effect is provided as TDD contains a pendulum in its design attached to the TDD frame substancially lower than the bundle axis ;

• Above this effect, the new Anti-galloping apparatus produces a pronounced damping effect to the bundle oscillations, due to the elastomer dampers connecting the TDD frame and the pendulum. The last has ample ability to rotate around the axis parallel to the bundle (Fig. 3). The TDD also uses pendulum effect for detuning of frequencies to make more difficult to reach resonance between torsion and vertical which is a dramatic situation causing lots of wind energy transfer from torsion to vertical movement. The effects of torsional oscillations damping down and phase shift are the main advantages of the TDD.

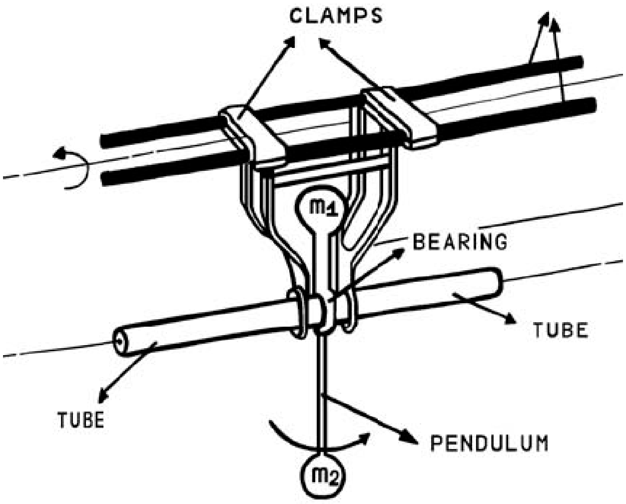

Fig. 3. The Torsional Damper and Detuner design. The two damping elements connecting the TDD frame and the pendulum free for swinging, are inside the tubes

3.2 The Detuning Pendulum against the TDD Device (comparative survey)

Practically no Antigalloping device exists which would try to damp down directly transverse vibration of the bundle at galloping (vertical mainly), its energy is too high; instead of that, decrese of amplitudes can be attained by additional separation of the bundle transversal and rotational frequencies, by installation of additional excentric masses along the OHTL span. These masses acquired the term Detuning Pendulums (Fig. 5). Their efficiency (moderate though in most cases) is proved by numerous applications in practice. Additional advantages are simplicity and, consequently, good reliability of the devices.

Fig.4. Photograph of The Torsional Damper and Detuner installed on the conductors (twin bundle)

Fig. 5. Detuning Pendulum installed on the twin bundle

Impossibility to have resonance between torsion and vertical modes prevents from wind energy transfer between torsion and vertical movement is typical for both means of Antigalloping protection. One can see explicitly now that the only but important difference between the TDD device and the detuning Pendulum is the damped movability of the pendulum in the TDD.

So the TDD, in extra, produces a phase shift between the two DOF which very much limits energy transfer when the galloping process is on.

A very simple but both important and demonstrative experiment has been carried out under the TDD device installed at the twin bundled conductors of a test Line [4]. It consisted in:

- mounting of the TDD on the twin bundle conductors of a test Line;
- angular deflection of the bundle; (max ±60 deg);

- releasing the bundle, observation of a decay process. The record of this experiment is shown in Fig. 6. Fixation of the TDD pendulum part turns it into ordinary Detuning Pendulum, correspondingly the bundle loses its integral damping efficiency – in the case under consideration, more than two times.

On the basis of Fig. 2, a somewhat ideal 'thought" experiment can be imagined – along this theoretically obtained orbit travels, in one case, the Pendulum damper, and, in the other case, the TDD device. A comparison reveals their different behavior.

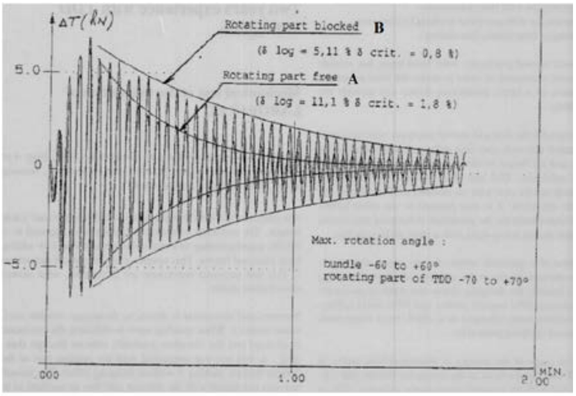

Fig. 6. Experimental decay of the bundle free swinging oscillations: (A) when the TDD pendulum is allowed to rotate while test; (B) when the TDD pendulum is blocked against rotation

If the Detuning Pendulum propagates along this orbit as a rigid body, the TDD with its pendulum responds to every change of the bundle angular position (the overall bundle rotation angle comes up to 80-90^0 peak-peak per one orbit turn) All the time a phase shift between optimal and real bundle positions is provided, this reduces energy influx to the main orbital movement of the bundle greatly. Finally, it gives higher efficiency of the TDD, see Annexe A1.

4. THE TDD DEVICES CREATED IN THE FRAMES OF GRANT INTAS ID 03-51-3736 AND RECENTLY

The intention to lower production costs of the TDD device led to searches of alternative conceptions of the damping unit (original TDD design produced in limited edition, had a production cost as high as 1,5-2,0 Keuros). After a series tests and probes, the damping unit was created on the basis of elastomeric balls placed between the two plates with recesses (Fig. A2, see Annex A2). Damping capacity of the structure was high enough (Fig. A5), dissipated power reached several tens of watts per oscillation.

4.1 The TDD-3.1 Model for triple bundle

Due to the more compact design of the damping unit and use of some standard details, the cost of this device was reducer sharply, up to 5-8 times cheaper than the original one. Photograph of the new TDD for triple bundle (Model 3.1) being mounted on the conductors is given in Fig. A3.

The main drawback of this TDD version which barred its wide application was poor behavior at low temperatures.

4.2 The Models TDD 8.1 and TDD 2.3

These models in their arrangement and design concepts are close to the initial TDD design as it was conceived and realized in Liege, with special attention to reach simplicity in their structures and higher workability in all the temperature range. More resistant to weathering and having a high damping elastomer is used in these constructions. A pattern of test to define damping value (for the TDD2.3) is given in Fig. A7, general views of the TDD devices are in Figs. A4 and A8.

4.3 Range of tests carried out

All the tests and trials are exposed in the Annexes A1, A2.

5. CONCLUSIONS

Besides splitting of torsional and transversal frequencies, the Torsional Damper & Detuner provides additional limitation of the bundle transversal vibrations due to blocking of energy transfer from wind. Damped rotation of the TDD pendulum ensuring a phase shift between the two DOF, which effectively limits energy transfer. This kind of action can be commented on as "active protection" provided with TDD. Typically the TDD tests demonstrate higher efficiency than the Detuning Pendulum.

For the sake of the TDD structural simplicity and production cost lowering, several designs of the TDD devices were projected and realized. They are getting more and more attractive to the Power Utilities.

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[4] Lilien, J.L., P. Pirotte, T. Smart, and M. Wolfs. A New Way to Solve Galloping on Bundled Lines. *Revue AIM* , Liège, No. 2, 1993, pp. 21-31.

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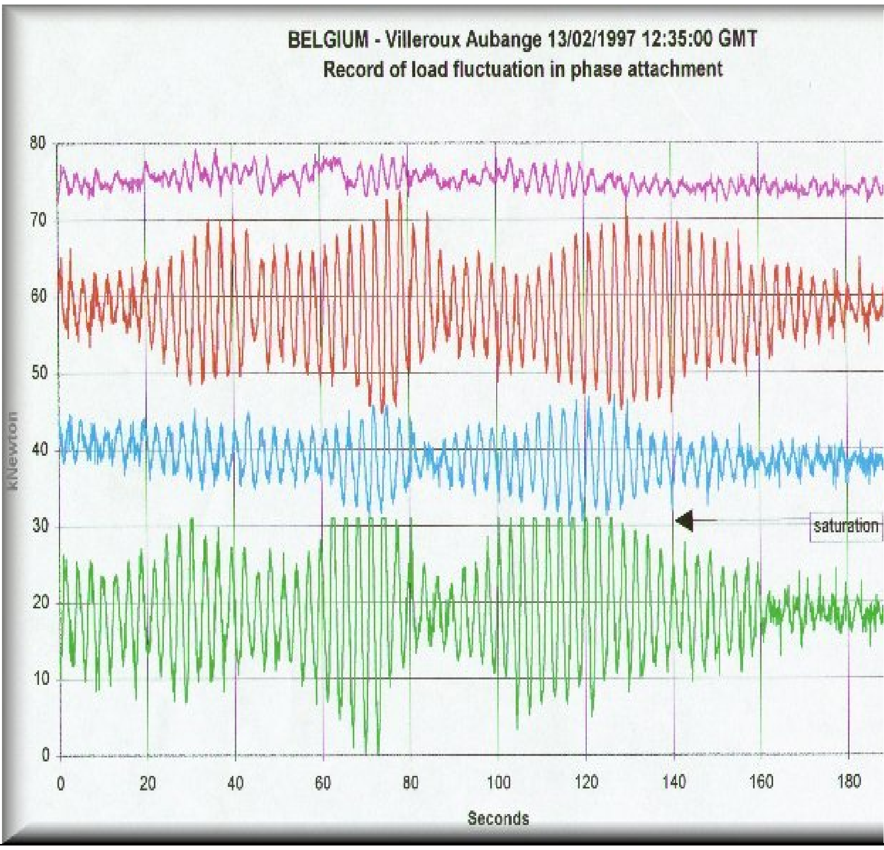
The problems of conductors vibrations in power lines, the use of spiral technology, The Lines protection against galloping

Comparative Field Tests of the TDD and the Detuning Pendulums on protection efficiency

Table A1

Automated recording while Galloping occasion was carried out at Villeroux Test Stand. It is given below as obtained on 400 kV Line section (twin bundle) well instrumented [5]. Transcript of records is listed in the right column.



THE CURVES BELONG TO:

TWIN PHASE WITH 3 TDD devices
PROTECTION 75-80 %

TWIN PHASE NO PROTECTION
(REFERENCE CASE)

TWIN PHASE WITH 4 PENDULUMS
PROTECTION 35-40 %

TRIPLE PHASE NO PROTECTION

Superior action of the TDD device has been fixed in this case (as well as in the other tests [4]).

2. Structural data

2 1 phase arrangement

span length (dead-ended) : 308 m

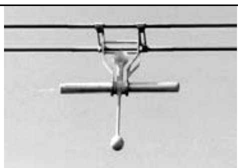
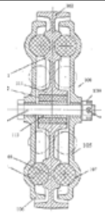
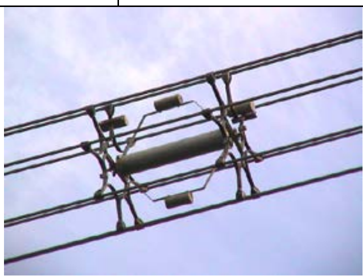
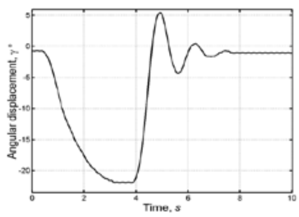
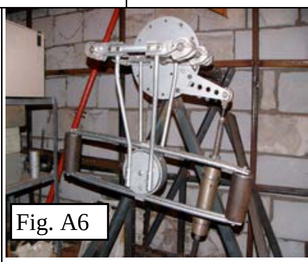
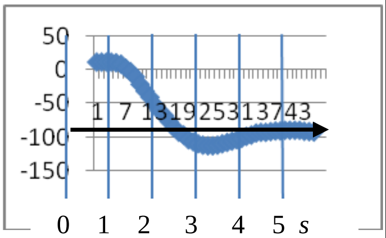
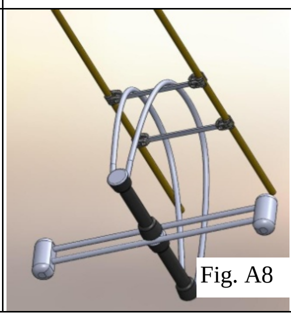
- One phase equipped with tripple conductor
- One phase equipped with twin horizontal conductor, spacered(referencephase)
- One phase equipped with twin horizontal conductors, with pendulum[4] (4 pendulum of 23 kg)
- One phase equipped with twin horizontal conductor, with TDD[6] (3 TDD of 33 kg)

2.2 conductor and bundle data

- conductor : 620 mm2 AMS (diameter 32.4 mm, mass 1 8 kg/m, torsional stiffness 300 to 400 Nm^2/rad)
- subconductor spacing : 0 45 m
- 6 spacers (with little eccentric massa)
- tension at 0°C /subconductor (no wind, no ice) :
  36 kN (sag approximately 6 m)

GENESIS AND EVOLUTION OF THE TDD STRUCTURES DESIGNED AND TESTED

Table A2

<No> Type Desig-nation	**Representative pictures**	**Type description**	**TESTS CARRIED OUT**	**DELIVERIES**
<1> **TDD-2**	 Fig. A1. The TDD-2 installed at Field Stand in Kazakhstan	The TDD-2 design as it was created in AIM-Ulg by a Research Group of Prof. J-L. Lilien (1990-ies)	Full set of Testing by Dulmison Company before dispatch. Tests at the Field Stand in Kazakhstan [6]	ELIA (Belgium) 1994, 20 devices **Official Recommendation of the Beneficiar**
<2> **TDD-3.1**	 Fig. A2  Fig. A3	An initial design of the TDD created in ESSP. The design was partly tested in field conditions	Transfer Function definition Tests [6] Energy dissipation loop Tests[6] Fatigue Tests, Vibration Tests[6] Full set of Testing Twin spacers (certified by Russian Standards) Log. Decrement Test, Field Tests **High Voltage exploitation Tests** Full set of the rubber dampers tests [6]	Tumenenergo (Russia) 2004, 20 devices
TDD-8.1	 Fig. A4. The TDD-8.1 installed at 1150 kV Power Line in Kazakhstan	Rubber Dampers are located inside tube. Detuning effect is created by additional weights		KEGOC (Kazakhstan) 2002, 30 devices **Verbal reports: good**
<**6**> **TDD-2.2*exp***	 Fig. A5. Log. Decr. Test  Fig. A6	The TDD-2.2*exp* sample and the test rig were designed for fatigue tests [6]. The TDD contained real clamps of a new design that had undergone wrench tightening and slippage tests		Test Report [6]
TDD-2.3	 Fig. A7. Log. Decr. Test  Fig. A8		Transfer function Tests; Log. Decrement Tests Hysteresis loop definition Tests Full set of Testing Twin spacers (certified by Russian Standards)	Design being patented in Russia Possible Purchaser: 126 pieces in case of Contracting with SC BACME S.A (Romania)