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Assymetricical Under Platform Dampers in Gas Turbine Blading's-Theory and Application

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ABSTRACT

Friction is regularly used in turbo machinery design as damping systems.UPDs are mechanical devices used to decrease the vibration amplitudes of the bladed disks. Codes are used to optimize during designing the UPD effectiveness in order to limit the resonant stress level of the blades. In such codes, the contact model plys the most relevant role in calculation of the dissipated energy at friction interfaces. One of the most significant contact parameters to consider in order to calculate the forced response of blades assembly is the static normal load acting at the contact, since its value strongly affects the area of the hysteresis loop of the tangential force, and therefore the amount of dissipation. A general method is estimating the static normal loads acting on dampers.

I. INTRODUCTION

Across boarda mode mechanical gadgets went for decreasing the cutting edge vibration of pivoting turbo apparatus depend on the utilization of erosion damping. Slip wonders originating from (a) sharp edge root joint, (b) cutting edge meshing along its

Tallness through covers, and (c) slipping movement of UPDs situated between two neighboring edges, are considered to restrain the plentifulness of wavering and the resulting HCF harm. Underplatform dampers are metallic parts with a specified geometry allowed to move inside a cavity put under the cutting edge airfoils. The divergent power because of motor revolution presses the Underplat form against the edge stages. At the point when the relative relocations because of gas stream and vibrations originating from motor revolution are sufficiently substantial to bring about slipping at the contact border, the subsequent circle disperses the excitation vitality through grinding. These uninvolved damping frameworks are object of preparatory point by point study with a specific end goal to apply the best blend of geometry and mass to accomplish the ideal abundance.

In a perfect world the contact surfaces must have a slant that grants tangential relative removals sufficiently expansive to bring about slipping. In addition, the contact surface causes an alternate restricted contact district on the off chance that it is adjusted or level, prompting diverse weight circulation affecting large scale slip or smaller scale slip conduct. The mass produces the inertial impact of the damper and the radial power which decides the preload on the contact surfaces.

The dynamic conduct of the edge Underplatform damper framework is registered by unraveling an arrangement of nonlinear equalization mathematical statements. Thus numerous creators have created numerical codes in view of calculations which iteratively hunt down the merging of the arrangement Outcomes are then accepted

by test ring estimations.These test apparatuses, genuine or sham cutting edges are cinched in an installation and are in contact with 1 or 2UPDs. They are cuddled against edge stages utilizing wires pulled with an "identical divergent" power. At the point when two sharp edges are coupled through an UPD, a significant scope of recurrence used to gather nonlinear FRF information incorporates two modular shapes, the supposed: "in stage" (IP) modular shape and 1801 "out of stage" modular shape. In Fig. 1 the diversions for the two edges are outlined for the two setups.

It is apparent that the solidness of the test rig varies altogether from the dynamic firmness of the plate; thusly full IP and Hoop frequencies of sharp edges in the two conditions will be essentially distinctive. In any case, relative uprooting shapes between cutting edges are significantly the same on circle and on apparatus, along these lines tests on the apparatus are substantial to evaluate damper execution.

A further comment is that IP movement is typically more basic than Truth be told experience demonstrates that dampers are by and large less powerful in IP modes, while IP excitation might be overwhelming, especially for high weight turbine stages close to the burning chambers.

A considerable measure of writing has been created about this given for instance a low motor request EOfor a turbine with 50 sharp edges, it is easy to figure how the stage postponement of the excitation symphonious power of two coterminous cutting edges is around 0.68 rad. On the off chance that this power example ought to energize a mode state of the bladed plate with the nodal breadth equivalent to the EO at its reverberation, the reaction of the framework would profit by a low measure of damping delivered by the UPD, since for this situation the relative removals between touching cutting edges are firmly like an IP diversion shape.

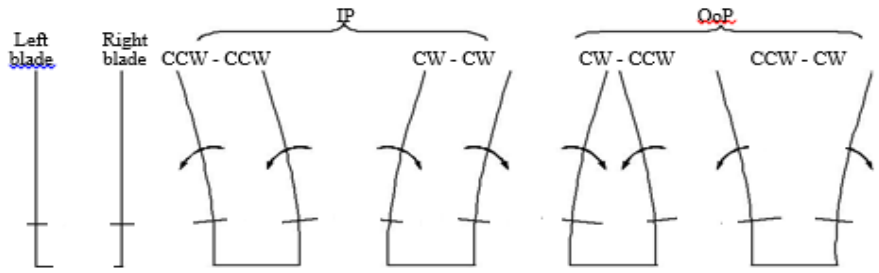
As an outcome, this paper goes for examining the damping viability of UPDs on a test apparatus, and gives the same significance to the investigation of the IP and Hoop mode. Two damper shapes are examined: (a) round and hollow and (b) 44 symmetric wedge or cabin rooftop damper. Results demonstrate that even level surface couplings, as in cabin rooftop dampers in IP mode, don't take after the basic slider kinematics and cause a contact shaking movement. The numerical model now being used, and utilized all through this paper to contrast computations and test results, incorporates this shaking movement trademark at the contact. It will be demonstrated that without this additional component, ordinary slider.

Contact hubs produce results which are in strife with trial perceptions.

II. SYNTHESIS OF THE FORCED DESIGNPROCESS

There are lots of distributions managing the Underplatform damper outline [1–4]. A large portion of them are particularly centered on the advancement of a computational arrangement for damper mass improvement. Two fixings are fundamental to the point: the contact model and the damper kinematic model.Full scale slip contact model is demonstrated by single slider application which in past writing was portrayed by more finish set of constitutive comparisons: 1D no movement slip state [9], 1D flexible stick–slip state [5], 2D in plane stick–slip state [10,15], 2D stick–slip-lift off state [126], 3D stick slip lift off state [17]. The last 2 and more finish of these contact models need nonlinear tangential and typical firmness and grinding coefficient to be known. Writing was delivered gone for foreseeing these qualities hypothetically and tentatively [12–17]. Miniaturized scale slip conduct is all in all displayed by method for large scale slip cluster [1, 11], while the investigative methodology is utilized as a part of refined Large scale contact model displayed by single slider which in past writing was

described by more finish set of constitutive mathematical statements



The dimensional no movement slip state [8], 1D versatile stick–slip state [9], 2D in plane stick–slip state [10,11], 2D stick–slip-lift off state 12, 3D stick–slip-lift off state [13]. The last two and more finish of these contact models need tangential and ordinary firmness and grating coefficient known. Writing was delivered gone for foreseeing these qualities hypothetically and tentatively [14–16]. Miniaturized scale slip conduct is when all is said in done demonstrated by method for full scale slip cluster (5), 11], while the diagnostic methodology is utilized as a part of refined lab approaches.

The kinematic model comprises the calculation of the relative removals at contact interface along tangential and typical course, with a specific end goal to ascertain the hysteresis circle through contact state move criteria. The relative movement at the contact surfaces relies on upon the speculation accepted to consider the nearness of the damper, i.e. the damper model.

Prior distributions [8, 22] consider the damper under the accompanying suspicion: (a) the damper kinematics is the of immaculate translational relative movement in the middle of stages and (b) the damper is constantly kept in full surface contact with cutting edge stages by outward constrain. Relative removals at contacts are accordingly expected to be in the contact plane as it were. The damper has inertial property, its masses is utilized just to decide the divergent power. Further improvements incorporate damper inactivity; typical and tangential firmness are displayed by springs associating a point on every stage surface to the damper focus of mass. In Ref. the genuine contact areas are considered, giving the damper a geometric augmentation which grants to separate the outright relocations of the left from the right side. The inertial properties are still gathered in the focal point of mass. In Refs. [21, 22], mass and versatile properties of the damper are completely considered through a limited component model.

The code created in a joint effort with AVI Group has been depicted in Ref. [2] and is here utilized. Its fundamental elements are condensed as takes after.

The bladed disk and upd are two model with reduced by component synthesis including the contact in the set of master nodes (Fi. 2). In the case analysis the code was generally used to couple the two blades system of the test rig to one cylindrical and wedge UPD.

The two structures are coupled in MATLAB utilizing 2D full scale slip contact components which consider stick–slip-lift-off state as per [17]. A nonlinear static FE investigation gives the determination of the genuine contact territory, in this manner it decides the suitable position of the contact components. The recreation is performed by applying the pulling stacks precisely similarly situated and with the same numerical worth utilized

amid the checks.

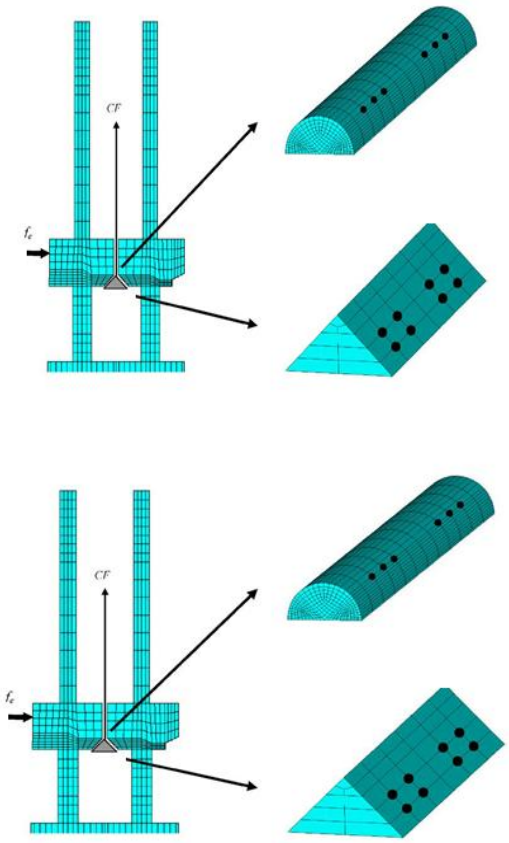


Fig. 3.models of the blade and UPDs. Spot on the platform dampers show the position of the contact.

III. EXPERIMENTAL SET-UP

Two edges have their base clasped in water driven press by method for a pressure riven barrel. The barrel shaped and wedge UPDs, appeared in Figs. 3a and b, are put in a hole underneath the cutting edge stages as mass M which delivers what might as well be called a genuine agent divergent burden, CF one fourth 400 N. One of the sharp edges is energized by method for an electromagnetic shaker. Ventured sine recurrence reaction testing is performed utilizing controlled consistent information power level, which is measured with a power transducer and kept steady through programming control. At every recurrence the input framework alters the shaker power keeping in mind the end goal to get an excitation sufficiency equivalent to the ostensible worth inside a resilience of 6%. On the off chance that the control circle is not accomplished inside a fleeting time on the grounds that the framework is unable to convey the information power level requested (power drop off wonder), the method is rehashed for a predetermined number of times until a greatest cycle number picked by the client is come to. For this situation the framework gathers the reaction got from the last emphasis, then begins to energize the structure with the following recurrence esteem. The reaction levels of the two cutting edges are measured with four accelerometers put two at the tip of every sharp edge and two at the edge stages tallness.

Test tests were subjected to reiteration with a specific end goal to acquire solid information. Step tests are performed with a stacking proportion CF/Fe 400which, as indicated by investigation, relates at full stick condition of the UPD against the sharp edge stages. The test is performed inside a scope of frequencies sufficiently wide to examine the change of the dynamic conduct of the two sham cutting edges communicating with the tube shaped damper for IP and modes.

Indicates two FRFs measured with the accelerometer put at the tip of the straightforwardly energized cutting edge. One FRF alludes to the structure without the damper (free-structure) and the other is the FRF with the completely stuck damper (stick-structure). The free- crest is well clear at 293 Hz, near the free-IP top at 296 Hz (not obvious in Fig. 6 on the grounds that covered by the free- mode). The round and hollow damper couples the two cutting edges in completely stuck condition creating the same tip adequacy of vibration for both, amid IP and vibration. Notwithstanding, the solidifying impact created by the damper for the two modes is distinctive: this is obvious by taking a gander at the applicable contrast in recurrence. The stick- mode is solidified up to 41Hz (+80%), while the stick-IP somewhat diminishes from 29 to 45 Hz. The tube shaped damper does not deliver a hardening impact in IP mode, the softening impact is because of the expansion of the mass of the damper to the spurious sharp edges. The distinctive change of the thunderous frequencies is brought about by an alternate kinematic conduct of the round and hollow Underplatform damper which will be talked about in the following segment.

IV. KINEMATICS OF THE CYLINDRICAL DAMPER IN STICK CONDITION

Tests in time space are performed amid IP and vibration. A sinusoidal excitation power with Fe 1 N the structure at the two resounding frequencies. Amid IP vibration, the barrel shaped damper demonstrates a moving movement which abstains from sliding uprooting at the contact surfaces. This is shown through LDV estimations. LDV bars measure vertical speeds at focuses 1, 4 on the stages (Fig. 7), and at focuses 2, 3 on the damper. Focuses 20 and 30 are the geometrical contact point in the middle of damper and Stages, they are adjusted along vertical headings to focuses 2 and 3. Figs. 8a and b demonstrates the sharp edge stages vibrating along the flat bearing in stage with the same sufficiency, while damper vertical relocations are two sounds at 1801, similar to stage vertical removals. Turn of the tube shaped damper is reliable with removals of the stages and with moving at the contact focuses. The cutting edge stages pivot clockwise when the damper turns counter-clockwise. It is anything but difficult to illustrate, from qualities recorded in Figthat amid IP vibration the barrel shaped damper encounters a moving movement around the contact lines damper/stage. This is gotten through a graphical development of immediate speeds or by a straightforward FE model where the mating contact is substituted by a pivot join between two hubs (Fig. 7). In a first estimate and because of the little removals of the damper, the FE harmoniousness of the mating hub relocations is comparable to the genuine moving contact movement. Besides, a flat movement of the tube shaped damper driven by the IP level vibration of the sharp edges can be assessed from the FE recreation. In the estimations under examination it can be construed from the stage accelerometers (Figs. 8a and b) that the barrel shaped damper is subjected to an even interpretation whose adequacy is greater than the vertical LDV estimations close to the damper edges (Figs. 8e and f). The same condition is recreated with the full numerical code which incorporates the flexible and sliding contact parameters (Fig. It is found that in the IP case no sliding happens, and, as it ought not out of the ordinary, the

qualities doled out to the contact parameters (tangential and typical contact firmness, rubbing coefficient) don't impact the reaction. Despite what might be expected the stick-coop is emphatically subject to contact solidness values, and subsequently it is a helpful test to evaluate the contact firmness at the contact interface. For this situation, indeed, a pivot limitation on the FE model overestimates the hardening impact. The utilization of contact components with allocated tangential kt and ordinary contact solidness is important; kt and know are tuned with bend fitting, under the supposition kn The quality k is a component of the quantity of contact components for contact region (Table 1), the decision is a bargain between the expanding computational time required by the expanding number of contact components and the requirement for a discretization of the contact region sufficiently refined that the point-load approach does not fundamentally separate from reality, i.e., a circulated contact load.

The blend of LDV and accelerometers estimations in time space (Fig. 11) exhibit that the damper direction results in a vertical Interpretation (Figs. 11e and f) amid OoP sharp edges vibration (Figs. 11a and b). An exceptionally minor damper pivot (obvious taking a gander at focuses 2 and 3 whose sufficiency of vibrations are appeared in Figs. 11c and d and even movement are because of a not indistinguishable symmetry of framework vibration and contact versatile conditions. parameter is not known from the earlier and it must be tuned against trial proof. In the estimation the quality 0.7 has been received through bend fitting of the damped hoop top measured at the tip of the two sham edges for CF/Fe ¼ 4. Correlation with trial information of the round and hollow damper direction for the coop mode is appeared in Fig. 18. Every casing is partitioned into three figures. The figure in the inside demonstrates the ascertained reenactment of the damper direction. The dashed line speak to the damper in static condition. Circle markers on the tube shaped surface demonstrate the position of the contact components. LDV pillars are the vertical lines hitting the damper base. The x-pivot and y-hub directions are the geometrical directions of the damper FE models. A scale variable of 200 is connected to both numerical and exploratory information to make them noticeable. The left and right figures indicate separately the straightforwardly and by implication energized cutting edge stages. The same graphical documentation utilized for the UPD holds.

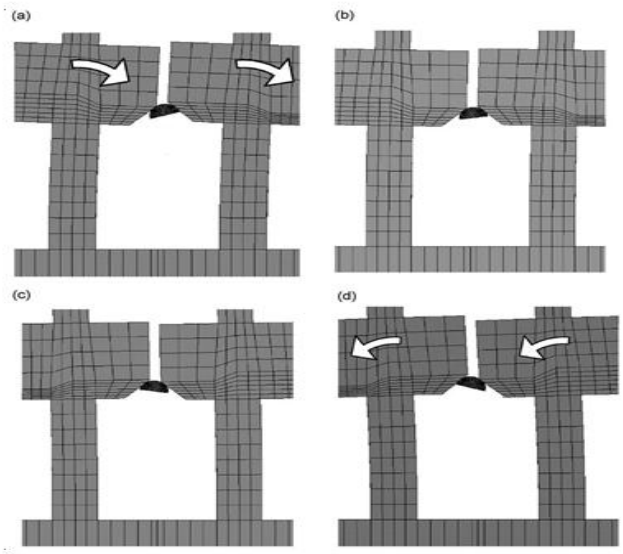


Fig 10. FE simulation of kinematics of the cylindrical damper,

V. WEDGE DAMPER IN STICK CONDITION

Rather, the IP modular shape relies on upon the CF/Fe proportion which in stick reaction expands the IP resounding recurrence of 14% as for the free-IP reaction. Level surface contacts for this situation solidify the IP mode and impact the damper kinematics.

5.1. Kinematics of the wedge damper

The kinematics of the wedge damper in coop vibration is described again by an interpretation movement: specifically Figs. 12 and d demonstrate that the vertical sufficiency of vibration is littler than the adequacy of the barrel shaped damper. In actuality IP vibration is portrayed by a moving movement between the two stages (Fig. 13). The damper pivot is littler than the round and hollow shaking movement and the solidifying impact of the IP modular shape obvious in Fig. 15proves that is impractical to reproduce the requirement with a "pivot" model. Since likewise for this situation the edge stages pivot clockwise when the damper turns counter-clockwise, either neighborhood lift-off of the contact districts happens, or the disseminated ordinary consistence of the level punch contacts of the damper permits the weight appropriation to shift locally inside one wavering. With a specific end goal to recreate this sort of contact, the position and the quantity of the contact components to put must be picked. A nonlinear static FEM investigation is useful to decide the genuine contact territory Ccnventional contact components.

Connected to the damper as in the test rig. The outcome is not touchy to the estimations of the contact parameters to enter in the business code in its contact component. The recreation demonstrates that eight expert hubs for each side set in the focal part of the contact range are an appropriate decision to couple the wedge damper with the fake sharp edges through the contact components displayed for erosion damping in the nonlinear numerical code.The same bend fitting technique utilized for the tube shaped damper is here used to redesign the estimation of contact solidness of the wedge damper case. The numerical FRFs match with great exactness the deliberate FRFs for given by business codes are utilized along the ostensible contact territory and a pulling burden is both stick-IP and stick-hoop mode if the same qualities utilized for the round and hollow damper are received (Fig. 14).

VI. CYLINDRICAL DAMPER IN SLIP CONDITION

They are the same tests in recurrence area are performed for lower CF/Fe values keeping in mind the end goal to have slip at the contact surfaces. Hence CF/Fe proportion is continuously diminished from 350 to 4. Fig. 16a demonstrates the pattern the FRF takes after for IP and hoop modular shapes.IP vibration shows up verging on obtuse to CF/Fe proportion, and damping in IP mode is small to the point that recurrence reaction tests at reverberation (Fig. 16b) must be restricted to Feo4 N, because of the procurement framework qualities. Amid these tests, LDV estimations of stages and damper are taken; every one of them indicated unadulterated moving movement of the round and hollow damper. Keeping in mind the end goal to survey damper conduct at the most elevated conceivable excitation, LDVestimations in time space have been taken up to Fe ¼ 9 N, where FRF step sine tests are unrealistic because of the disappointment of the criticism control.

As Fig. 17 appears, measured removals do well contrast and moving movement as anticipated by FEM stick conditions: truth be told the LDV estimations on the base of the tube shaped damper together with the yield

signs of the four accelerometers demonstrate the same diversion shape measured in stick condition, scaled of a component marginally littler than 11 at the tip of the cutting edges. The round and hollow damper is viable for the coop mode (Fig. 16a), and its impact is plainly unmistakable as of now for little Fe values (Fig. 16c).

A nonlinear figuring was performed with the numerical code keeping in mind the end goal to recreate the gross-slip in hoop vibration. For this situation the erosion coefficient is the contact parameter which decides the measure of damping. This

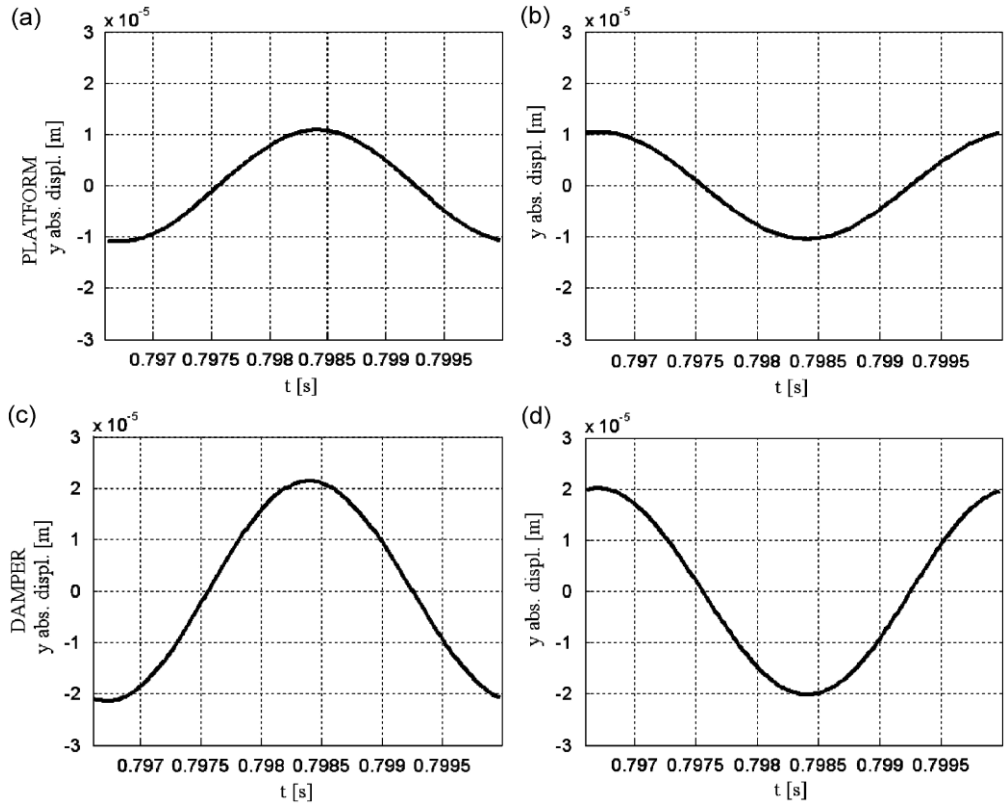


Fig. 17. Cylindrical damper, CF/F_e ¼ 39, IP mode: platforms ((a), point 1 and (b), point 4) and damper ((c), point 2 and (d), point 3) vertical motions.

VIII. EFFECT OF THE WEDGE DAMPER IN SLIP CONDITION

The similar tests performed on the round and hollow damper were rehashed additionally for the wedge damper. Fig. 20 demonstrates the dampd FRFs for CF/Fe proportion diminishing to the estimation of 5. The wedge damper turns out to be as viable in decreasing the crest adequacy as the round and hollow damper.

LDV estimation of Fig. 21 demonstrates that focuses 1 and 2 move in stage and also focuses 3 and 4, as on account of the round and hollow damper where focuses 1–2 move upward and focuses 3–4 move descending then again inside one swaying. It is here shown that this confirmation is conversely with the kinematics coming about because of a contact model which predicts the full contact between the two damper/stage level surfaces. For this situation truth be told the accompanying speculation must be assumed: When two sham cutting edges vibrate in an IP bowing mode the redirection removals for the two edges is the same, subsequently the point between the two stages stays steady amid movement. This edge is precisely equivalent to the edge between the two contact surfaces of the wedge damper, under stacking condition. Just for this situation the wedge damper

has the likelihood to slip at the contact keeping the level surfaces in full contact with the cutting edge stages amid the entire IP vibration. Fig. 22 demonstrates a FEM recreation utilizing a straight imperative mathematical statement as a part of request to speak to the kinematics relating to this work of art ""slider"" model; it can be plainly seen that this contact model creates a descending movement of point 1 while point 2 has an upward movement; reverse c**ir**cumstance for focuses 3 and 4.

Additionally for this situation the consideration is basically centered around IP reaction. Essentially to the round and hollow damper situation where the damping sum is low, the most extreme level of outer excitation in IP estimations is limited by the power drop off wonder. I

n this cases, a most extreme level of Fe 13 N has been utilized, just about three times the greatest quality satisfactory for the round and hollow damper, inferring that the wedge damper is more viable in damping IP vibration than the tube shaped dampers. More exact correlations are unrealistic because of the absence of solid estimations, since amid every one of the estimations performed around the IP reverberation the most extreme emphasis number presented in Section 3 is come to.

were performed with various excitation frequencies and a gathered reverberation recurrence of 302 Hz was picked comparing to the most noteworthy reaction sufficiency.

A nonlinear recreation was performed for the IP mode at CF/Fe ¼ 12. The damper direction comparing to one swaying was then plotted for the top reaction acquired by the figuring. The subsequent kinematics uncovers a moving direction with incomplete lift-off of the contact surfaces inside one time of swaying (Fig. 23). Two sets of hubs for each segment has been picked and put on the contact surfaces as proposed by the nonlinear static FEM investigation (Fig. 2). The FE result is reliable with the wear delivered on the UPD.

The halfway lift-off of the contact surface is demonstrated by the name over a contact point. For this situation the contact strengths go to zero. It is conceivable to note that damper hubs still in contact with the stages are dependably in stick condition. Nonlinear conduct of the wedge damper is because of the lift-off and stick condition rotating state, not by tangential slipping. The recreation predicts the nonappearance of damping in concurrence with exploratory discoveries where the redirection shape comes about nearly in a mono-consonant swaying as appeared in Fig. 24a and b. The reenactment demonstrating fractional lift-off of the wedge damper in conjunction with its shaking movement kinematics is likewise in concurrence with the recreation performed in Ref. [23]. Reenactment for hoop mode indicates results like those as of now talked about for the coop barrel shaped damper (transcendent vertical interpretation prompting a gross-slip contact state); they won't be examined here.

VIII. CONCLUSION

The connection between the kinematic conduct of two delegate sorts of UPDs, tentatively recognized by method for a novel methodology in light of LDV estimations, and their damping ability has been investigated. The investigation of a round and hollow and wedge UPD was centered on two specific first twisting methods of a two sham cutting edges framework: "in stage IP" and 1801 "out of stage hoop" modular shapes.

The kinematic conduct of round and hollow and wedge dampers, when sharp edges vibration is coop, is significantly indistinguishable: LDV estimatg course, ignvestigation demonstrates that likewise damping is entirely equal: for an estimation of CF/Fe ¼ g4, which guarantees gross-slip for both dampers, the two dampers

deliver an abundance decrease, contrasted both with free and to stick conditions, of moreg than 90% in both cases.

Amid IP vibration the tube shaped damper encounters an immaculate moving movement at the contact focuses, which makegs it verging on incapable for damping and creates a straight element conduct for all CF/Fe proportions. LDV estimations demonstrate a damper revolution in concurrence with inflexible body i.e., inverse to the pivot of stages.

On account of the wedge damper, tests recognized a kinematic conduct interestingly with the unbending body slider model: truth be told turn is observed to be inverse to the pivot of stages, while the slider model suggests an equivalent point of revolution both in sign and greatness. The shaking movement happens in stick and in expected slip cases, and gis allowed by the nearness of flexible consistencein the heading ordinary to the contact surfaces. The conduct is not direct, and damping, albeit pgresent, is much lower than as per the slider model. The shaking of the wedge damper as for stage pivots measured by the LDV proposegs fractional lift-off of the contact surfaces happen. Nonlinear numerical greenactments support tgrial proof. The FE models werge tuned to the straight reaction of the test rig. Nonlinear contact components were set by static examination with FEM business programming. Nonlinear full sgcale slip contact model was embraced subsequengt to the correlation gwith trial information gr the coop mode are great, both for the dynamic conduct of the fake sharp edges and for the kinematics of the two dampers. The reproducedg reactions foresee a prevaglent vertical interpretation of the two UPDs that is steady with LDV and accelerometers estimations. The correlation demonstrates that HBM linearizationg is a profitable apparatus to speak to UPDs working in gross-gslip administration. IP reenactmgent uncovers a shaking movement kinematics of the wedge damper good with LDV estimations proof. A critical conclusion is that the study here dsplayed discounts all unadugllterated unbending body models, similar to slider models, and additionally models with no rotational level of opportunity, similar to mass-point models. Rather, no less than two hubs along the stature of the contact surface are required to speak to the tilting movement of thedamper as for he sharp edge stages.

REFERENCES

[1] B.D. Yag, C.H. Menq, Charctrization of contact kiematics and application to the design of wedge dampers in turbomcinery blading: part 2-predicton of forced respose and experimental verification, ASME Journal of Engineering for Gas Turbine and Power 120 (1998) 418–423.

[2] L. Paning, W. Setro, K. Ppp, Optimization of interbladefriction damper design, Proceedings of ASME Gas Turbine and Aeroenine Congress and Exhibition, Munic, 2000-GT-541.

[3] E.P. Ptrov, D.J. Ewis, Analytical formulation of friction interface elements of nonlinear multi-harmonic vibrations of bladed discs, Proceedings of ASME Turbo Expo, Amsterdam, 2002-30325.

[4] G. Csba, Modelling of aicroslipfrction damper subjected to translation and rotation, ASME Gas Turbine &Aeroengine Congress and Exhibition, Indianapolis, 1999-GT-149.

[5] K. Sanliturk, D.J. Ewins, A.B. Stanbridge, Underplatform dampers for turbine blades: theoretical modelling analisand comparison with exerimental data, ASME Gas Turbine &Aeroengine Congress and xhibition Indianapolis, 1999-GT-335.

[6] M.H. Jareland, Experimental investigation of a platform damper with curved contact areas, Proceedings of

SME Design ngineering Technical Conference, Pittsburgh, DETC2001/VIB-21391.

[7] M. o¨ cker, A. Kessar, T.H. Fransson, G. Kahl, H.J. Rehder, Comparison of models to predict low engine order excitation in high pressure turbine stage. Proceedings of the 10th International Symposiu on Unsteady Aerodynamimcs, Aeroacoustics and Aeroelasticity in Turbomachines, Durha, NC, USA, 2003.

[8] J.P. Den Hartog, Forced vibrations with combined coulomb and viscous friction, Transaction of ASME (1931) APM-53-9, pp. 107–115.

[9] C.H. Mnq, J.H. Griffin, A comparison of transient and steady state finite element analyses of the forced esponse of a rictionally damped beam, Journal of Vibration, Acoustics, Stress, and Reliability in Design 107 (1985) 19–25.

[10] C.H. Mnq, P. Chidamparam, J.H. Griffn, Friction damping of two-dimensional motion and its application in vibation control, Journal of Sound and Vibration 144 (3) (1991) 427–447.

[11] M. Saliturk, D.J. Ewns, Modelling two-dimensional friction contact and its application using harmonic balance ethod, Journal of Sound and Vibration 193 (2) (1996) 511–523.

[12] B.D. Yng, M.L. Chu, C.H. Menq, Stick–slip-separation analysis and non-linear stiffness and damping characterization of friction contacts having variable normal load, Journal of Sound and Vibratins 210 (4) (1998) 461–481.

[13] B.D. Yng, C.H. Menq, Characterization of 3D contact kinematics and prediction of resonant response of structures having 3D frictional constraint, Journal of Sound and Vibration 217 (5) (1998) 909–925.

[14] J. Szwedwicz, M. Kisel, B. Ravindra, R. Kellrer, Estimation of contat stiffness.