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Response to Comments on: "Nonlinear phenomena, bifurcations, and routes to chaos in an asymmetrically supported rotor-stator contact system" by Philip Varney, Itzhak Green [J. Sound Vib. 336 (2015) 207-226]

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ABSTRACT

The authors would like to thank the discussers for their interest in the paper. The discussers raise several objections to the original work; namely, that the state-space equations of motion were derived incorrectly, thus rendering the original results incorrect by association. In actuality, the error in the original state-space equations (Eq. (16) in the original work) is typographic only. This, in conjunction with a typographic error in Table A1, prevented the discussers from replicating a subset of the original results (though the discussers were able to replicate many of the results presented in the original work, despite the presumed error in the equations). These typographic errors are rectified here. In addition, results are presented here corresponding to the solution that would have been obtained had the state-space equations been incorrect in the manner presumed by the discussers. Finally, the discussers state that the results presented in the original work do not adhere to physical principles because the steady-state solution in one case indicates contact even though the linear response to imbalance is less than the radial clearance. This seeming discrepancy is also addressed here.

1. Response

The authors would like to thank the discussers for their interest in the paper and their keen attention to detail. We acknowledge that the error in Eq. (16) is merely typographical. The proper equation, as also provided by the discussers, is:

$$\begin{Bmatrix} x'_1 \\ x'_2 \\ x'_3 \\ x'_4 \end{Bmatrix} = \frac{1}{n^2}\begin{bmatrix} 0 & n^2 & 0 & 0 \\ -\omega_{xx}^2-\phi_L & -2\zeta\varpi n & \mu\phi_L-\omega_{xy}^2 & 0 \\ 0 & 0 & 0 & n^2 \\ -\mu\phi_L-\omega_{xy}^2 & 0 & -\omega_{yy}^2-\phi_L & -2\zeta\varpi n \end{bmatrix}\begin{Bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{Bmatrix} + \begin{Bmatrix} 0 \\ \epsilon\cos\tau \\ 0 \\ \epsilon\sin\tau - g/n^2 \end{Bmatrix}, \quad (1)$$

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Table 1
Symmetric rotor parameter sets.

	PS 1	PS2	PS3	PS4	PS5	PS6
m (kg)	15	15	5	15	15	5
k (N/m)	$2.0(10)^6$	$2.0(10)^6$	$1.0(10)^6$	$2.0(10)^6$	$2.0(10)^6$	$2.0(10)^6$
c (N s/m) (ζ)	(see below)	(see below)	1341.6 (0.3)	3834.1 (0.35)	3834.1 (0.35)	2529.8 (0.4)
ϵ (m)	$5.0(10)^{-5}$	$8.0(10)^{-5}$	$4.0(10)^{-5}$	$5.0(10)^{-5}$	$4.0(10)^{-5}$	$8.0(10)^{-5}$
δ (m)	$9(10)^{-5}$	$1.5(10)^{-4}$	$9.0(10)^{-5}$	$9.0(10)^{-5}$	$9.0(10)^{-5}$	$1.5(10)^{-4}$
μ	0.25	0.15	0.2	0.25	0.25	0.2
$\sqrt{k_c/k}$	20	20	20	20	20	32.34

where

$$\phi_L = \omega_c^2 \frac{r-\delta}{r} h(r-\delta) \tag{2}$$

The original MATLAB script is correctly coded with the proper equations. Additionally, Table A1 should read as provided here in Table 1 (note that the last line should read $\sqrt{k_c/k}$). Taking these corrections into account, all of the results and conclusions reported in the paper are correct and no further changes are warranted.

2. Some selected results

To elaborate, the discussers presume that the first and third state-space equations were incorrectly derived and simulated in the following form:

$$x'_1 = x_2/n^2 \tag{3}$$

$$x'_3 = x_4/n^2 \tag{4}$$

Since $n >> 1$, and because x'_1 and x'_3 represent time-normalized velocities, this (presumed) error is tantamount to setting the system linear momentum to zero following each time step; thus, no matter the applied force (in this case, gravity and imbalance), the system will persist at the original displacement initial conditions. For completeness in reviewing the original work, a simple test is performed here: the ‘incorrect’ system is simulated to ensure to the discussers that this particular error was not responsible for the discrepancy in the results. The initial condition was chosen for this test case to be $u_y = -0.5\delta$; the results are provided in Fig. 1. The results show that the same rotor response would be obtained regardless of the system parameters, with this result being equal to the system displacement initial conditions. The rotor responses provided in the original work [1] clearly do not suffer from the state-space error presumed by the discussers. The discussers are encouraged to verify this conclusion using their own code.

For completeness, the results presented by the discussers are replicated here by our own code using the parameter

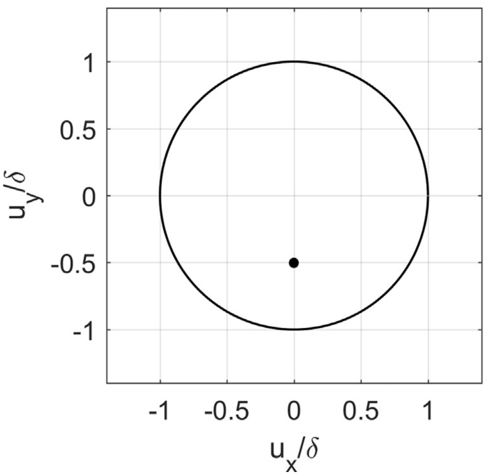

Fig. 1. Solution that would have been obtained had the typographic error been present in the simulation code.

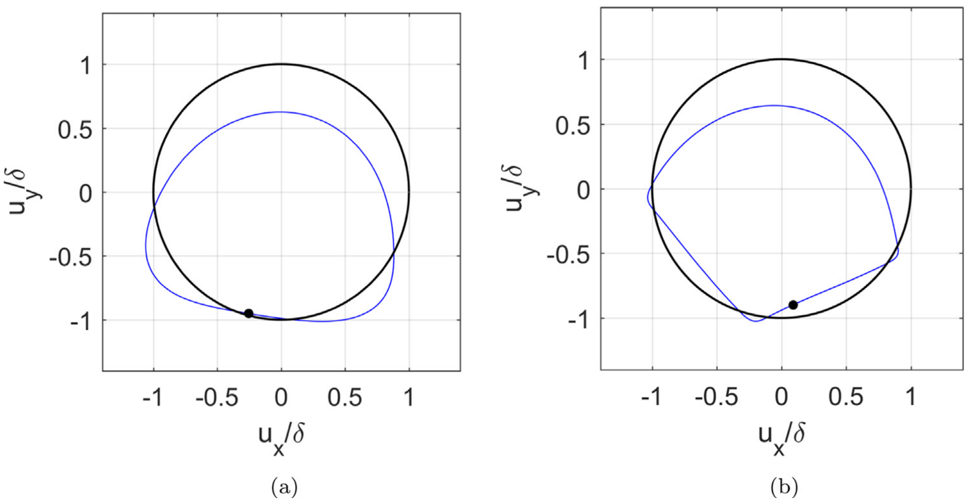

Fig. 2. Results corresponding to (a) $k_c/k = 20$, and (b) $\sqrt{k_c/k} = 20$.

$k_c/k = 20$. As seen in Fig. 2a, the result from our code clearly aligns with that provided by the discussers. In reality, the results in the original work correspond to the parameter $\sqrt{k_c/k} = 20$, as verified again in Fig. 2b. The authors again thank the discussers for bringing this discrepancy to light.

In Section 4.2 of their commentary, the discussers solve the non-contacting equations analytically and derive a bound beneath which steady-state contact is not expected to occur. The discussers then claim that the response shown in Fig. 15 [1] is incorrect, precisely because the steady-state solution in the absence of a fixed radial clearance δ is less than δ itself. The authors would like to remind the discussers that initial conditions can, and often do, dramatically influence the final solution obtained via the numeric integration. Fig. 15 [1] was simulated for initial conditions corresponding to $y = -0.5\delta$ and $x = \dot{x} = \dot{y} = 0$; in this case, the transient response causes the system to reach a limit cycle where contact does in fact occur in the steady-state solution (see Fig. 3a, which has been recalculated here corresponding to the conditions of Fig. 15 in Ref. [1]). If initial conditions are selected corresponding to a state-space point on the steady-state response to imbalance, the system does indeed converge to a non-contacting solution (see Fig. 3b). This behavior is characteristic of non-linear systems such as that studied here; perhaps including a small amount of contact damping would reduce this effect. Still, it is important to note here that the results shown in Fig. 15 [1] are correct, contrary to the discussers' claims. It should also be noted that a similar phenomena is observed by Feng et al. [2], who observe that a perturbed rotor will sometimes remain in contact with the stator even if the steady-state response to imbalance is less than the rotor-stator clearance.

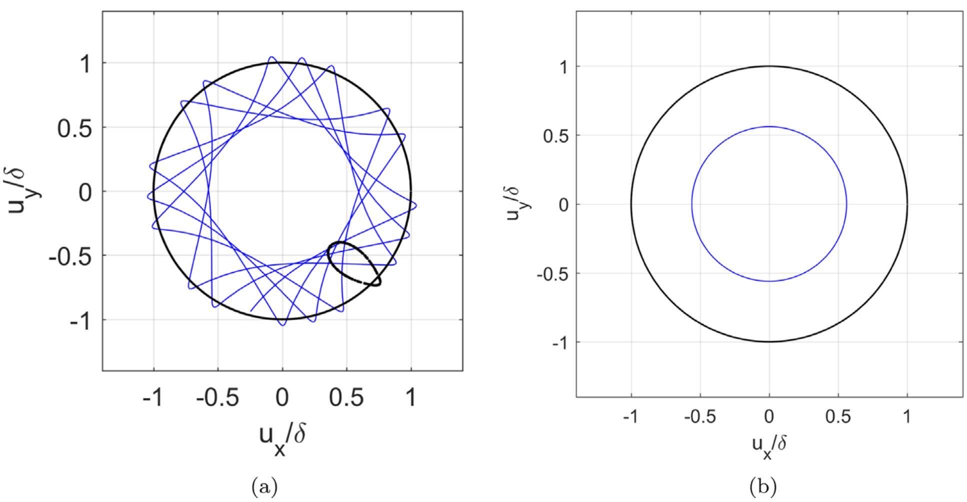

Fig. 3. The effect of different initial conditions on the solution from Fig. 15 in Ref. [1] (a) $y_0 = -0.5\delta$, all other conditions zero, and (b) initial conditions corresponding to a state-space point $(x, \dot{x}, y, \dot{y})$ lying on the steady-state solution imbalance orbit.

3. Conclusions

The original paper merely contained two typographical errors caused in the paper production, namely: "1" instead of "n^2" in the matrix of Eq. 16 [1], and "k_c/k" instead of "$\sqrt{k_c/c}$" in Table A1. Everything else in the paper is correct and consistent with these two corrections. The original MATLAB code did not suffer from the two typographical errors and, hence, the authors stand behind the analysis, results, discussion, and conclusions, as presented in the original paper.

References

[1] P. Varney, I. Green, Nonlinear phenomena, bifurcations, and routes to chaos in an asymmetrically supported rotor-stator contact system, J. Sound Vib. 336 (2015) 207–229.
[2] Z.C. Feng, X.Z. Zhang, Rubbing phenomena in rotor-stator contact, Chaos Solitions Fractals 14 (2002) 257–267.