Institution: Aberystwyth University

Unit of Assessment: Mathematical Sciences (UoA 10)

Title of case study: Improved parametric resonance of a vibrating screen

1. Summary of the impact (indicative maximum 100 words)

A novel application of parametric resonance (PR) is described, which has improved the effectiveness of a vibrating screen used for size-sorting of crushed rock. These improvements have had an economic impact on the Ukrainian company that makes the screens: the mathematics developed in Aberystwyth permits a stable, high amplitude PR-regime to be found, reducing the damage to the screen mesh and increasing its longevity. This new technology is allowing the company to reduce costs and equipment downtime and is enabling them to gain a market advantage by being able to sort wetter materials than previously.

2. Underpinning research (indicative maximum 500 words)

Vibrating screens are used to separate crushed stone into different sizes, for example in coal and ore mining and various chemical industries. In the past, parametric resonance has been mainly considered as an undesirable phenomenon, but in 2007, L. Slepyan and V. Slepyan realized that a PR-based vibrating screen could eliminate many of the drawbacks of existing screens. A PR-based screen compares favourably with conventional size-sorting machines, in which transverse oscillations are excited directly, because it has not only a larger amplitude of vibration, but also insensitivity to dissipation over a rather wide range. During L. Slepyan's visit to the UK in 2007, he worked with Movchan and Mishuris to start an intensive programme of research on the topic, using mathematical models of oscillations and waves in lattice structures.

In 2009, a patent was issued to the Slepyans on the excitation method and structure of the screen [3.1]. At that time, the nonlinear dynamics of such a machine had been numerically simulated and the first PR-based screen was built in Loginov and Partner Mining Company (Kiev, Ukraine). L. Slepyan subsequently visited Aberystwyth in 2010-12, and is now employed here. He and Mishuris have been actively working together within the EU FP7 IAPP project PARM-2 [3.5], coordinated by Mishuris, to improve the screen and develop related theory [3.2,3.3].

The stable operation of a PR-based machine for the grading of granular materials requires careful design and set-up, which can be achieved on the basis of the mathematical analysis of its dynamics. Numerical simulations allow for the refinement of the domains of optimal parameters, where the parametric oscillations are excited and where the analytically-obtained steady oscillation regimes are stable. The models developed are also of use in other PR applications, although this is probably the largest machine to use PR at this time.

The modelling problem is described by a system of two coupled nonlinear equations [3.4], which permit an exact solution in the case that there is no damping associated with the transverse oscillations. In the fully nonlinear regime, harmonic analysis is used to give explicit expressions for the amplitudes of longitudinal and transverse oscillations as functions of the external force amplitude and frequency. It is remarkable that in the case of the resonant excitation, where the external force frequency coincides with the frequency of the free longitudinal oscillations, the amplitudes are independent of the viscosity of the granular material. In addition, lattice waves and pre-stress were studied, to induce particle fracture off-lattice.

The determination of the boundaries of the PR domain in the frequency-amplitude plane is based on the linear formulation. The PR arises in the nonlinear problem in almost the same frequency region predicted by the linear analysis, slightly shifted towards the higher frequencies. The transverse oscillations, both regular and irregular, abruptly decay on the boundaries of the PR region.

3. References to the research (indicative maximum of six references)

[3.1] V.I. Slepyan, I.G. Loginov and L.I. Slepyan, The method of resonance excitation of a vibrating sieve and the vibrating screen for its implementation. Ukrainian patent on invention No. 87369, 2009.

[3.2] Slepyan, L.I., Mishuris, G.S., Movchan, A.B. (2010) Crack in a lattice waveguide. Int. J. Fract., 162, 91–106.
DOI: 10.1007/s10704-009-9389-5

[3.3] Mishuris, G; Movchan, A; Slepyan, L. (2009) Localised knife waves in a structured interface. Journal of the Mechanics and Physics of Solids, 57, 1958-1979.
DOI: 10.1016/j.jmps.2009.08.004
REF2 Submitted.

[3.4] Slepyan, L.I., and Slepyan, V.I., (2013) Modeling of parametrically excited vibrating screen. J. Phys.: Conf. Ser. 451, 012026.
DOI: 10.1088/1742-6596/451/1/012026

[3.5] PARM-2, Vibro-impact machines based on parametric resonance: concepts, mathematical modelling, experimental verification and implementation, PIAP-GA-2012-284544-PARM2, 1.8m euro, 01/01/2012 – 31/12/2015.

4. Details of the impact (indicative maximum 750 words)

The research on PR and lattices by L. Slepyan and Mishuris has been conducted in close collaboration with V. Slepyan, Chief Designer at the Loginov and Partner Mining Company (LPMC), where a vibrating screen was designed and built based on the idea of PR.

LPMC now makes and sells equipment for size-sorting based on PR for field testing, currently only within the Ukraine; the equipment is known as GEPARD. They are popular because they are effective at separating *wet* granular material: in a traditional vibrating lattice, the dissipation is highest at the centre, and the material gathers there, but with PR not only is the amplitude larger for a given amount of input energy, but the dissipation is better distributed so material does not clump. This is expected to give LPMC a distinct market advantage.

At first, the screens broke too frequently (roughly every few hours), due to cracks developing both longitudinally and around the edges. As the Director General of LPMC writes: “Close communication of V.I. Slepyan with Professors Leonid Slepyan and Gennady Mishuris (Aberystwith University) and the experiments carried out by the Company resulted in better understanding of the screening machine operation process and developing solutions to increase the fatigue strength of the screen and stabilize the parametric resonance. As a result of the solutions, the screening machine service life has been increased”. By the end of July 2013, the operating time for the vibrating screen had been increased to a period of several days.

The key improvements due to the mathematical modelling are:

1. a more careful delineation of the parameter space in which the stable PR modes are to be found;
2. a suggestion to change the way in which the screen boundary is clamped at its edges, so as to eliminate edge cracks in the lattice;
3. changing the lattice structure of the screens, to have a mesh with elliptical or circular holes, and a distribution of hole sizes which decrease towards the edges of the screen;
4. most significantly, inserting a small gap between the screen and the exciter motor is remarkably effective in preventing cracking of the lattice.

Each screen costs between one and eight-hundred dollars, depending on its country of manufacture and the quality of the material. The whole vibrating machine sells for only a few thousand dollars. Thus the screens represent a significant proportion of the running costs. The result of the modelling – that is, the reduction in the frequency at which the screens fail due to cracking - is that there is less manual intervention required by the operators, and a reduction in the amount spent on replacement screens, currently by a factor of about four.

To increase the longevity of the screens, they are often used below maximum efficiency, i.e. outside the optimal PR regime. The industry standard is that a screen should last for about 10 million cycles, roughly two weeks, and this is now the goal for modelling and development of refinements to the equipment.

Mathematical models developed for the oscillations and waves in lattice structures and the determination parameter space of the regular PR oscillations resulted in the improvement of the machine and opened a way for other PR applications.

5. Sources to corroborate the impact (indicative maximum of 10 references)

[5.1] Letter and contact details for the Director General of LPMC.