"Spontaneous" acceleration of freely rotating helium II and related phenomena in pulsars

Dzh. S. Tsakadze and S. Dzh. Tsakadze

Physics Institute, Georgian Academy of Sciences
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It is shown that a decelerating rotating vessel with helium II can become accelerated jumpwise without external action.

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In 1966, Andronikashvili, Gudzhabidze, and Tsakadze[1] have shown that when rotating He II is heated above the λ point, the quantized vortices are preserved for a long time also in the He I. It is particularly important that the vanishing of the vortices takes place in abrupt jumps that occur a long time (~20 min) after their total preservation. In 1969, Packard and Sanders[2] have shown that the number of vortices changes in a similar jumplike manner in rotating He II that is being accelerated or decelerated. Thus, a change in the rotation conditions of He II is accompanied by relaxation processes that are peculiar to superfluid liquids and are due to the formation of long-lived metastable states. It is known that it is precisely the relaxation of the rotation of a pulsar that made it possible to identify it as a superfluid neutron star.[3,4]

In 1972 Packard[5] suggested that the jumplike vanishing of groups of vortices in a pulsar is the cause of the vortex acceleration. Indeed, if the vortices likewise vanish in groups in a decelerating rotating neutron liquid, then their angular momentum will be transferred to the solid shell of the pulsar and the latter will become accelerated. The relaxation process accompanying this acceleration will apparently be different from the relaxation process that occurs after the pulsar is accelerated as a result of the deformation of its shell. Indeed, at least one of the accelerations of the pulsar PSR0532 differs from the remaining ones in the character of its subsequent relaxation.[6]

Let us compare the estimated changes in the number of vortices in the experiments of Packard and Sanders with those in pulsars. They turn out to be quite different. Whereas in the former case the number of vortices did not exceed several dozen, and one to three vortices were produced or vanished after each jump, in pulsars, with $\sim 10^{17}$ vortices, about 10^{13} vortices vanish after each jump.[4] This estimate, based on the assumption of total conservation of the vortices during the entire period between the accelerations, is maximal. But even the minimal estimate obtained by counting the number of decayed vortices needed to explain the magnitude of the jump is quite large, 10^9–10^{11} vortices per jump.

This raises the question whether these so different situations have anything in common. It seems to us that the facts and arguments presented below enable us to answer this question in the affirmative.

We used an instrument analogous to that used to simulate pulsar relaxation after a starquake.[4] The instrument was a cylindrical vessel with inside diameter 1.5 cm, constructed in two variants: 1—with partitions in the form of flat disks parallel to the bottom and cover of the vessel and spaced 7 mm apart; 2—the same vessel without partitions. The vessel height was 7 cm. The vessel was rotated in helium vapor on a bearingless magnetic suspension. The speed of revolution was registered with a system connected to the M-1000 regulating machine. After the start of the acceleration, which was effected by an external pulse, the vessel was smoothly decelerated by the helium-vapor viscosity.

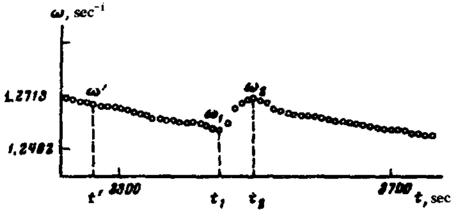

FIG. 1. Time dependence of the speed of revolution (in logarithmic scale). The time is reckoned from the instant of pulsed acceleration of the vessel. ω' is the velocity calculated from the conservation law, starting with which (i.e., from the instant t') the vortices that decayed at the instant t_1 were preserved.

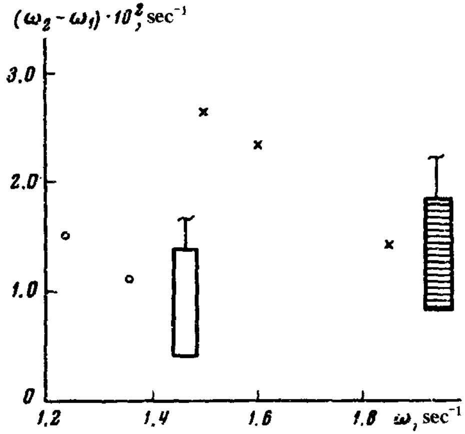

FIG. 2. Dependence of $\omega_2 - \omega_1$ on ω_1.

A typical plot of the speed of revolution ω on the time t is shown in Fig. 1, in the form of part of the curve that follows the relaxation of helium II after its artificial acceleration, as described in[4]. Against the background of the linear decrease of the velocity we see the vessel accelerates at the instant t_1 and its speed is changed by $\omega_2 - \omega_1$. Thus, we have succeeded in experimentally verifying the possibility of spontaneous acceleration of a decelerating rotating superfluid liquid. The dependence of $\omega_2 - \omega_1$ on the rotation speed is shown in Fig. 2.

Using the angular momentum conservation law we can show that the number of vortices decaying during the time of the jump is 100 to 190 in the first variant of the vessel and 35 to 50 in the second.

Let us count the number of "extra" vortices that vanish in each jump from each unit area. It turns out to be 100 to 300 vortices/cm^2 in the experiments of Packard and Sanders, 60 to 100 in the first variant of our instrument, 20 to 30 in the second variant, 10 in the pulsar PSR 0833-45, and 20 vortices/cm^2 in the pulsar PSR 0532. The difference between these numbers is in any case much smaller than the difference between the total numbers of the metastable vortices, which lie in the interval from 1 to 10^{13}.

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