The vibration records referred in the letter quoted have been analysed, and Fig. XIII. shows the results obtained from them, about which it may be observed that great difficulty was experienced in finding a suitable place in the ship where the recorder (vide Fig. 13 of my former paper) could give good readings, and it will be also noted that the amplitude of the vibration is very small.

All the propellers we have lately manufactured to be turbine driven have been put straight into the dynamical balancing machine, and we have found that it is quicker and cheaper than only balancing on a knife edge, and we have the further satisfaction of knowing that such propellers are in true running balance.

DISCUSSION.

Mr. J. C. Bradfield (Sydney University Engineering Association) said that it gave him great pleasure to be present and to move a vote of thanks to Mr. King-Salter for his interesting paper. Before doing so he would like to say that some weeks ago the University Engineering Society held a meeting and decided to come into the Institute of Engineers of Australia. The postal ballot was completed on Monday last, and the vote was unanimously in favor of coming into the Institution. This was the second combined meeting of the three resident Societies held in Sydney. The next one would be held under the auspices of the Sydney University Society. He believed it would be the last. It would be held the day after the Council held its meeting. He said:—In attempting to discuss Mr. King-Salter's carefully prepared paper, giving the results of further experiments in the dynamic balancing of rotating masses, one is handicapped in not having heard or read his previous paper.

Happily in the years to come this will be the fault of the individual in not attending the meetings—at present it is due to the various Societies not being amalgamated.

Dynamics is the science of motion, and it is clear that a body in perfect static balance may not be in perfect dynamic balance, and that, with a rotating body out of balance, the amplitude of the vibration of the restraining spring will at a certain speed reach its maximum, then fall, but at a higher speed will increase, but will not reach the first maximum, and so on, there being, as the speed increases, a series of maxima amplitudes, each less than the previous one, until with infinite speed (providing the material rotating were infinite in strength) the vibration would be zero.

It is interesting to note that Mr. King-Salter and Commander Cleary, in different spheres, were experimenting on similar lines. The spider evolved by Mr. King-Salter gives the location of the mass out of balance, and by trial and error the out of balance can be corrected.

The anomalies of the variation of the amplitudes arising from using springs of $\frac{1}{2}$in. dia. and $\frac{3}{4}$in. dia. steel are interesting, and probably some simple explanation will be forthcoming as the result of further experiments, though I must confess at present I cannot offer any suggestions why the $\frac{3}{4}$in. spring gave amplitudes 3 and 4 times greater than the $\frac{1}{2}$in. springs.

The lessening of the vibration after the propellors of the 'Loongana' and 'Niagara' had been dynamically balanced was, of course, to be expected, but it is none the less interesting to know it actually occurred.

The question of dynamic balancing has been interesting to Civil Engineers since the earliest days of railway engineering. Certainly no machine has had so much time and money spent in perfecting its dynamic balance as the

railway locomotive, but one realises that though the balance obtained in locomotives is far from perfect, it is not due to want of thought on the part of designers, but to inherent limitations due to the type of the machine. The horizontal reciprocating forces are balanced by the rotary forces, which leave unbalanced the reciprocating vertical forces. These produce the hammer-blow effect on rails, permanent-way and bridges.

It is a rapid change of thought from the balancing of rotating masses, such as the propellors of the 'Loongana' and 'Niagara,' to the harmony of the universe. Mr. King-Salter's experiments and results have shown us some of the difficulties he met with, and those difficulties enable one to realise the problem which confronted the Creator when the multitude of stars were set in motion in the heavens. The problem of the dynamic balancing of rotating masses existed before man was, and with the great scientific advancement which the future holds the problem, as far as engineers are concerned, may become more involved, and all experiments, such as those outlined to-night by Mr. King-Salter, will add to our knowledge in attempting to solve the problem.

The speaker concluded by moving a vote of thanks to Mr. King-Salter for his extremely interesting paper.

Mr. F. P. Kneeshaw had much pleasure in seconding the vote of thanks, and at the same time to thank the Engineering Association for inviting the Electrical Association to be present that evening to listen to the paper. The members of the Electrical Association were naturally interested in the paper, as electrical engineering was closely associated with high-speed drives. The members of the Electrical Association would be glad if Mr. King-Salter would push on with his experiments, and, if possible, reach some finality. His attention had been drawn

yesterday in the office to some papers from London with regard to devices introduced to reduce the noise, particularly with respect to blowers and other rotating machinery. If Mr. King-Salter could carry his experiments further, and produce some commercial instrument, it was probable that the firm whose enterprise caused them to produce this anti-noise device would have to go out of business. He did not propose to attempt to discuss the paper, and would content himself by seconding the vote of thanks and again thanking the Association for the invitation to be present.

THE PRESIDENT: In the discussion of the paper we would be glad to hear from any visiting engineer.

MR. FRED. HOWARTH said that there was one thing with regard to reciprocating machinery, such as a high speed petrol engine, which to the present day gave trouble with its periodical vibration. The vibration was very excessive if a certain speed was exceeded. The balance was such that you did not notice the ill-effects from it at first, but upon going to a higher speed you got further vibration. He would like to know if Mr. King-Salter could go into that aspect, as the method by which he located the out of balance was so ingenious. He was glad to hear the paper that night, as the system appealed to him greatly. He said there was a little periodical vibration set up in the fixed joint. He had used a larger pin, in many cases mounting both in the same plane, and so got rid of a good deal of the vibration. Mr. King-Salter took a good deal of the sag out of the mounting of the Holden Coupling by means of driving with the single dog. He had much pleasure in supporting the vote of thanks, and the idea was no doubt the most ingenious he had seen published, and he had closely followed many balancing propositions published from time to time in the engineering journals.

MR. WILKINS said he had a suggestion to make with regard to springs. The springs of any given compression strength had a natural period of vibration, and up to that period a larger spring might quite considerably vibrate and synchronise with the axle springs of the motor at the particular time. That, he thought, was the explanation of the vibration which occurs, as referred to by the last speaker.

MR. MYERS wished to make one suggestion in an endeavour to assist in getting more accurate results in the initial readings in the preliminary test. That was in order to get the direction of the maximum vibration, and, at the same time, get the amplitude, use should be made of the well-known Oscillograph. It was merely a suggestion, and he was not prepared to design an equipment on the spur of the moment.

MR. J. P. TIVEY said that, following on Mr. Myers' remarks, a similar idea had occurred to him as the result of a remark passed by Mr. Julius during the reading of the paper. He believed the Oscillograph would give a precise determination both of the position and quality of the maximum vibration at any time. There was one thing he would like to ask Mr. King-Salter. It was hinted that balancing might be done with the axis vertical. At Rugby, where blower propellors were balanced with the axis vertical, the method of drive was a very flexible steel wire rope. He did not know whether Mr. King-Salter had considered such, although, as he said, somewhere in the papers it was hinted that vertical shaft balancing had been thought of. The remarks of some of the previous speakers seemed to cast some doubt on the ability of this apparatus to detect the position of out of balance masses. It seemed to him that the apparatus could not be more simple than it was, and it did the work for which it was designed. The difficulties appeared to

arise from the fact that there were really two simple harmonic disturbances taking place, and at the periods of the vibration these two disturbances were not the same. Continuing, he said that it was only to be expected that complications would arise in determining what out of balance really was. A suggestion which might possibly be adopted was to bring the system into static balance—which Mr. King-Salter did not approve of.

MR. NEWBIGIN wished to thank the Association, as a visitor, for the welcome that evening. He said he felt, as far as Mr. King-Salter's paper was concerned, a little like Rip Van Winkle. When he was actively engaged in the dynamic rotating of masses the only apparatus furnished him was a blue pencil and profanity. Mr. King-Salter had eliminated the blue pencil. There were one or two points in connection with the paper which he would like further information upon, because it was a matter which interested all of them, and the interest was greater day by day as the high-speed prime mover came into use. He gathered from the paper that Mr. King-Salter's balancing had been done below critical speeds. Those who had had much to do with the balancing of turbine-driven machinery were prepared to admit that balancing below critical speeds was comparatively simple. It was a peculiar fact that you could balance machines below critical and above critical, and yet have them out of balance at critical. Every machine had its own natural period of vibration. It seemed to be almost impossible to balance accurately when the small disturbing element was not sufficient to support the speed. He explained in detail the different variations with regard to balance in the machines at Newport. He had had experience in running two turbine-driven alternators in parallel. They could get those perfectly balanced at normal speed. If you got the building vibrating you would disturb the

balance of both machines, which were individually perfectly balanced. It was a question of the greatest importance. Some of the speakers had drawn attention to the advisability of static balancing. The experience of most men was that static balancing was a delusion and a snare. Usually the balancer would rather have his stuff straight from the lathe than the balancing table. A good many years ago, in the works where he then was, they tried balancing a machine in which the bearings were supported in two springs, approximately at right angles to each other. That machine was abandoned, and he thought it was probably because the balancers found it more difficult than the old method. For the man who was going to balance with a blue pencil the oil damp bearing was of marvellous assistance. He was interested to know by Mr. King-Salter's paper that the rotors he was balancing were originally started in a vertical plane. He was not quite clear from the paper how the vibration was to turn into horizontal vibration. The figures given by Mr. King-Salter for lag were most interesting. He was speaking of normal speed. They used to reckon up to 45 degrees was a fair average for the balance; 45 to 60 did cover 90 per cent. of the balancing cases. Mr. King-Salter had drawn attention to the out of balance effect at 180 degrees. Another point which was particularly noticeable in very long turbine-driven units was the transmitted vibration. Those machines with the oil damp bearing that transmitted their out of balance effect into a place where you did not expect to find it was one of the joys in the phases of balancing. With regard to the spider which Mr. King-Salter illustrated in his paper, it would be interesting to know if it made any alteration in the centrifugal force. With regard to driving he did not know whether Mr. King-Salter had seen that copper strip device which was used by Sir Charles Parsons in his

tests of rotors. The speaker had seen it in the "Electrical Review" a few months ago. It would be an expensive matter, because he did not think the copper strip lasted more than two or three times. It was possible that for experimental work Mr. King-Salter would find that it would enable him to obtain more accurate data.

PROFESSOR SUTHERLAND said that it seemed to him that the natural period of vibration of the system in any given case was likely to have an important bearing on the results which might be expected. He would like to ask Mr. King-Salter whether he did not think that therein lay an explanation of the apparent anomalies which he mentioned in his paper. The anomaly, for instance, in which the heavier spring gave a larger vibration than the lighter spring. Considering the possible effects of the natural period of vibration, it seemed to him possible that it might prove undesirable to select a speed at which the maximum amplitude was obtained for attaining the desired measurements. That speed would give the maximum measurements and make it easier to determine accurately. It seemed to him that the conditions of the two ends of the shaft might be easily rather rather different when the natural effect of vibration was taken into consideration. He would say in practice the two ends of the shaft would be different. Accordingly the measurements obtained at a speed to correspond with the natural period of vibration would not accord with the two ends for any given arrangement of out of balance weights. If these ideas were correct, he should be inclined to think that the measurements should be made at some speed which did not accord with the speed of natural vibration. With regard to the method in which the measurements could be made, there was a suggestion once made to him which might be worth mentioning. The idea was to mount on either end of the shaft a short copper

cylinder. He thought the direction of maximum vibration might be determined, and also the measure of its magnitude of vibration.

MR. G. M. HOSKINS said he was very pleased to be present. He referred to the very successful balancing carried out by Mr. King-Salter at the Lithgow Iron and Steel Works.

THE PRESIDENT: I have nothing of technical value to add to the discussion, but I am sure that Mr. King-Salter will not mind me referring once more for a few moments to the question of the new Institution. One of the objects of the new Institution is to secure greater co-operation between the representatives of the different branches of the profession. I think you will readily agree that the likely value to be obtained by the object of the new Institution has been perfectly illustrated to-night by the discussion. No one, in New South Wales at all events, had any doubt at all but that the objects of the new Institution were right. One important thing remains, that these objects shall be effectively carried out—that is, that each member of the new Institution will bring personal service. I think you will all agree, too, that this meeting to-night, which is the most representative I have ever had the pleasure of seeing, is a very vivid piece of evidence that we are going to have that enthusiasm which will make a success of the new Institution. I wish to say no more on the subject, except to add that in future, as Mr. Bradfield has pointed out, you will not meet as representatives of separate Societies, as most of you do here to-night. You will attend by right. Further, we have heard from Mr. Newbigin to-night that he is thankful for his welcome. In future he will come to a meeting such as this is in any State by right also. All these things are going to lead to that bright future to which we certainly look for the engineering profession. We hope we

are going to come more into our own. I repeat that it must be very gratifying indeed to those who have hoped that this Institution was coming into being to find such convincing evidence which this meeting discloses to-night. He wished to convey to Mr. King-Salter the appreciation of the meeting, and to express to him formally the thanks of the joint meeting for the very interesting address he had given. He would ask them to carry it by acclamation.

MR. KING-SALTER, who was received with applause, said: Mr. President and gentlemen, I thank you very much for the kind way in which you have received my address to-night. I came here with a certain feeling of trepidation on account of the many disappointments I had had in not having reached the finality I had hoped. But having consented to give you a paper, I thought it was best to give you what I had. The discussions cover a very wide field, and I have a little difficulty in answering all the points which were raised. Mr. Bradfield made a remark about not reaching the same maximum at a higher speed. I entirely agree with him there, especially under the circumstances that with the particular type of balancing gear we have used we could not have springs controlling the motion. I may say in a sense that my remarks here are covered by what Mr. Newbigin said about critical speed. We have a mass rotating, and if any portion of it is not exactly in such a position as to be in dynamic balance, which covers really static balance, you get unbalanced forces when that mass is rotated, causing vibration. Under the conditions we have in balancing with this particular appliance, those unbalanced forces are operating at every revolution; and as the speed increases, so they increase with that speed, and at a certain period you have the speed of rotation corresponding with the time of vibration, and the natural period of vibration

of the springs which are operating to reduce that vibration. At a certain particular speed, which I referred to as the period of maximum amplitude, you have the out of balance forces and the springs exactly coinciding. I think that under this you get an extremely sensitive condition. I gave one example—to which Mr. Hoskins referred—where a mass of two tons was balanced at the low speed of 180 to 200 by this method, at which speed it corresponded with the period of vibration of the springs. I say if you get such a sensitive condition as that, I am of the opinion once you get the balance at that critical speed that you will not get any vibration at any higher speeds. I would also go so far as to say that in those particular rotors to which Mr. Newbigin referred, where he said at certain critical speeds you got vibration, that that rotor was not in perfect balance. If it had been you would not have got vibration, unless there was some other cause which disturbed them. I tried to explain in my last paper the conditions which are necessary for any particular rotor to be in perfect balance. I will briefly refer to it now. That is, that the centre of maximum must be in at the centre of rotation of that specified static balance. The dynamic balance with each lamina of the rotor along the length of the shaft to the centre of mass of each of these lamina must lie in the plane of that lamina. You would then have a condition of perfect balance. If you have a perfect balance I cannot see how you would get vibrations at any speed. My experience of turbine rotors is that they balance at the low speed. We have never found that with high speeds we get any vibration at all. I may be wrong, but I do hold the opinion that if you can balance a thing at that critical speed you have it right for all time. Mr. Kneeshaw hopes that I shall push on with my experiments. I hope to be able to do so. Mr. Howarth referred to reciprocating engines. I have not

dealt with that matter at all. I have confined myself entirely to the question of propellors and turbine rotors. The question of reciprocating engines has been most exhaustively dealt with by far abler men than myself. I do not know that I am going to take on that difficult problem. With regard to the Holden Coupling and the method of drive, I do not know whether I made myself clear on that point, but I have come to the conclusion that no matter what kind of drive you have you are going to get upsetting factors. We have come to the definite conclusion that the only way to eliminate is by declutching the driving gear from the shaft. With regard to the apparatus to which Mr. Myers referred. I tried to mark that instrument, which is very much on the line of the one he mentioned. I wanted to get a mark on a disc. I found it was not instantaneous. I have asked various electrical friends of mine, but we have never been able to get anything sufficiently rapid to mark that disc so as to be able to use that instrument. They spent a lot of time over it, too. Referring to Mr. Tivey's remarks, a gentleman two years ago, in discussing my paper, suggested the same idea that he did with a vertical drive. I said then I had no doubt that such an arrangement would be very suitable up to a certain point for comparatively light weights. There, again, I think the flexible shaft with the wire rope would induce different actions. Professor Sutherland has apparently not read my paper of two years ago, in which I introduced the subject by saying a few words about balancing conditions. I said that if you attempted to create a static balance on a knife edge, or other similar method as a knife edge, that you would probably in ninety times out of one hundred create it in the wrong place, because you could not tell at what end of the rotor you had to take the weight off. Whereas if you leave the static out of balance alone and put what-

ever your rotor has into the machine and rotate, it would not only fix up any static out of balance, but also any dynamic out of balance, and the two natural laws combined would tell you that it resolves itself into a condition of the dynamic out of balance, which has to be created by the two weights. Mr. Newbigin gave some very interesting experiences, and, as I have just added as regards Professor Sutherland's remarks, the static balance does not give a true balance by any means whatever. I did not quite catch what Mr. Newbigin said about horizontal motion in regard to this particular balance. As far as I could gather, he said he did not quite understand how we could pick up the out of balance in the horizontal direction instead of the vertical.

MR. NEWBIGIN: I said I could not understand how you obviated the vertical action altogether.

MR. KING-SALTER: There is a rough model here of what we have adopted. It can move horizontally, but not in any other direction. All we have done now is to reverse the position. We have given the horizontal action and blocked any vertical action. When the flying weight comes round and has got into the right position for actuating the whole mass, it causes the whole thing to swing against the springs. The question was mentioned of taking out the natural vibration of the spring. In my supplementary remarks this evening I said we were on the point of seeing whether that natural period of vibration of the springs did have any effect on it by having a few further experiments by jumping the motor in one direction and allowing it to swing. Up to the present we have all our results at the period of actual vibration. When masses are revolving in an apparatus of that sort you reach a certain point where the period of speed of revolution corresponds with the periodicity of the springs, and

you get a maximum amplitude at that particular speed. You revolve that mass in one direction. You revolve it in another, and you get the maximum amplitude again at the same speed. The whole point of what we are doing is to work on the maximum amplitude. We get satisfactory results. One gentleman referred to a polished copper cylinder on the end of the shaft, which made an electric contact. If you will think for a moment you will see that that appliance is a glorified arrangement of the blue pencil. As I explained in my paper two years ago, it was very rough, and absolutely unreliable, because you could not get the scriber to mark the shaft at the same period in one direction than in another. Another thing that upsets this synchronising with the springs is that the angle of lag is so varying at almost every revolution. I marked the shaft with the scriber step by step and at the end, when we passed the maximum vibration. These marks were made at 180 degrees, and at a lower speed he said they would get a mark on a shaft. Continuing, he said: I do not know that I have any further remarks to make to-night. I am much obliged to you, gentlemen, for the kind attention you have given me. It has been a pleasure for me to come. He concluded by inviting them to inspect the model which he would demonstrate for their information.

THE PRESIDENT: This concludes the formal business of the meeting, gentlemen, and if you wish to take advantage of seeing the model, it is here for you to do so.