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THE HONORARY ADVISORY COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH

BULLETIN No. 2.

PRELIMINARY REPORT

ON

RESEARCHES ON SOUND MEASUREMENT

WITH REFERENCE TO THE

TESTING OF FOG SIGNAL MACHINERY

By

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Canada

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TESTING OF FOG SIGNAL MACHINERY

BY

PROFESSOR LOUIS V. KING, M.A., D.Sc., F.R.S.C.,
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Although powerful sirens have been in use in all maritime countries for nearly half a century, there was until recently comparatively little accurate scientific information available regarding the way in which sound-waves were actually generated by such apparatus. It has long been known that existing types of sirens or steam whistles are extremely inefficient, that is, that little of the power furnished was converted into sound of such a character or quality as would penetrate a desired distance in foggy weather. The extent to which it is possible to protect a trade route in this way from accidents due to fog depends ultimately on the power, penetration and reliability of the fog alarms which can be installed and operated at a given cost. It is evident, therefore, that as in other branches of engineering, one may expect advances to be made as soon as the quantities dealt with shall have been subjected to *measurement*. For instance, wireless telegraphy as a practical art reached nearly to its full development in little more than a decade. The reason for this rapid advance lay in the fact that precise methods of measuring *electrical quantities* were at hand when the first experiments proving the practicability of radiotelegraphic transmission were carried out.

The difficulty in the development of what may be called "Acoustic engineering" has been the almost total lack of sound-measuring instruments. The development of fog-signal machinery has also been retarded by the fact that experimental tests are not only very costly but have had to be conducted at isolated stations far removed from laboratory facilities.

In spite of these difficulties, Canada has been among the most progressive of maritime countries in the experimental development of fog-alarm systems. The type of fog-alarm which has found favour in Canadian waters, and has been installed in many localities, is a modified form of compressed-air siren known as the "diaphone". The original diaphone was invented by Dr. Owen Hope-Jones. Its utilization for fog-alarm purposes was first suggested by Lieut.-Col. Anderson, Chief Engineer of the Department of Marine and Fisheries of Canada, who, with his chief assistant, Mr. B. H. Fraser, determined from numerous tests the lines along which the diaphone evolved into full-sized fog-signal apparatus in the hands of Mr. J. P. Northey of Toronto.

The writer first became interested in fog-signal machinery as a subject for scientific investigation in the summer of 1912, when accompanying Professor Howard T. Barnes on a cruise to the Straits of Belle Isle with the object of making a close study of icebergs which in the North Atlantic constitute a serious menace to the safety of navigation. Accommodation was provided on the Canadian Government lighthouse tender "Montcalm" during one of her routine cruises to the Gulf of St. Lawrence. In this way very exceptional facilities were available for the study of the Canadian lighthouse and fog-signal system. It was observed that the note given by the "diaphone" at a distance was very nearly a pure tone. In these circumstances there seemed to be some possibility of devising an instrument for accurately *measuring* the sound and of studying in a scientific manner the effect of atmospheric conditions on its propagation. On making a study of the means available for the measurement of sound, it happened fortunately, that an instrument was at hand for the purpose as a result of the researches of Professor A. G. Webster of Clark University. On communicating with Professor Webster with regard to carrying out a scientific study of fog-signal apparatus, he not only offered to supervise the construction of a "phonometer" specially designed to measure the sound from the diaphone, but placed at the writer's disposal the entire experience of the Clark University laboratory in the matter of sound-measuring instruments.

Professor Webster's "phonometer" was tried out during a first series of tests carried out with the assistance of Mr. H. H. Hemming at Father Point, Que., in September, 1913. Through the courtesy of the Department of Marine and Fisheries, permission was given to operate the diaphone when necessary for the purpose of the tests. Through the kindness of the Postmaster-General, authorization was given to make use of the mail tender, "Lady Evelyn" during the experiments. The Webster phonometer proved to be a success from the first and was employed in carrying out a number of acoustic surveys in the neighbourhood of Father Point. In this way much new information was obtained with regard to the behaviour of sound under a variety of weather conditions. It was found that the wind was by far the most important factor in causing the sound to behave in an irregular manner: on some occasions the sound was entirely lost, to be picked up again at a greater distance. These "silent zones" have often been met with at sea and constitute a source of danger if by any chance a mariner should be so unwise as to estimate his distance from a fog-alarm by the loudness of the signal. These silent zones are by no means always present, but occur under special conditions of wind, both at the surface of the sea and in the upper regions of the atmosphere. In general the results of the acoustic surveys showed that the loudness of the sound fell away in a very erratic manner according to weather conditions. It is sometimes asserted in text-books on acoustics that the loudness of the sound should decrease according to the inverse-square law, that is, at double the distance the loudness should be reduced to one-fourth, at triple the distance, to one-ninth, and so on. This "law", which would hold in an ideal atmosphere, perfectly stagnant and free from eddies and inequalities of temperature, was found to be not even approximately true under conditions at sea, even on the calmest days.

During the 1913 tests, considerable advance was made in another direction, *i.e.*, in the determination of the "acoustic efficiency" of the diaphone. In all branches of engineering dealing with apparatus for converting some form of energy into another, it is of the greatest importance to know the amount lost or wasted in the process. The proportion of power thus wasted can be measured in the case of steam-engines, internal-combustion engines, electric motors, hydraulic and steam turbines and many other forms of machinery. It is obviously the main object of a mechanical designer to keep such losses as small as possible and the history of engineering shows that progress in this respect has followed advances in the development of the *theory* of the machines under consideration and in the construction of instruments for the precise measurement of the physical quantities involved.

In the case of fog-signal apparatus practically nothing was known respecting the losses of power incurred in the production of sound. In the case of ordinary musical instruments it was known from the work of Lord Rayleigh, Webster and others that the proportion of power converted into sound was exceedingly small, in many cases less than one part in a thousand. Simple calcula-ions indicated that if the atmosphere were to transmit sound-waves without loss, it would require only about one-third of a horse-power to give a signal audible at 10 miles. As a matter of fact more than 100 horse-power have to be expended during a blast to give a signal of sufficient power to carry this distance on a specially calm day. In order to obtain some information on the nature of the large losses implied in this statement, the writer determined to attempt to measure by a specially devised method the actual proportion of power converted into sound in the trumpet of the diaphone itself. The method was based on the theory of sound-producing apparatus and was specially worked out for the purpose in hand. In carrying out tests, use was made of sensitive electrical thermometers. Several series of tests gave fairly concordant results. Under normal conditions it was found that about two and a half horse-power of the power supplied could be utilized as sound. This represented about eight per cent. of the output of sound which might be emitted from an ideal siren in which all the energy of the compressed air was utilized in the production of acoustic signals.

This was as far as the work had proceeded by the end of September, 1913. Further work was made impossible by the outbreak of the war and the diversion of activities to war problems. On the formation of the Advisory Council for Scientific and Industrial Research, application was made in June, 1917, for a grant to continue the work undertaken in 1913. As soon as assurance was forthcoming that a grant would be available, preparations were made during the summer of 1917 to attack some of the outstanding problems still awaiting solution. As in 1913, permission to carry out the tests was kindly given by the Department of Marine and Fisheries and the use of the pilot tender, C.G.S. "Eureka" was granted for the occasion. It was decided to carry out acoustic surveys with much more complete meteorological data than had been obtained previously. This was made possible through the action of the Meteorological Observatory in delegating Mr. John

Patterson to take charge of upper air investigations. With the assistance of Dr. A. N. Shaw of MacDonald College, numerous records of wind velocity at altitudes of several thousand feet were obtained by sending up small pilot balloons and following their motion by specially designed theodolites. At the same time an acoustic survey was carried out by means of the Webster phonometer with the assistance of Lieutenant E. S. Bieler, who kindly volunteered his services for the work during leave of absence from active service.

It was found that often on the clearest days the wind a few hundred feet from the level of the sea was entirely different in direction and magnitude from that at the surface. Such conditions have an important effect in refracting the sound-waves and, in many ways as yet imperfectly understood, affecting their propagation to a distance.

It is hoped in the future to obtain as complete a series as possible of such combined observations, the graphical representation of which may be expected to be of service to the fog-signal engineer.

An important problem which was solved during the 1917 tests was that of studying the *quality* of the signals given out by the diaphone. When any sound-producing instrument is sounded, it rarely happens, except in the case of specially designed laboratory apparatus, that a pure note of single pitch is generated. The note in most cases is a complex mixture of the *fundamental*, accompanied by a large number of notes of higher pitch called *overtones*. The accurate analysis of complex tones has only recently been achieved through the work of Professor Dayton C. Miller of the Case School of Applied Science of Cleveland, Ohio (U.S.A.). By means of an instrument of his invention called the "phonodeik", Professor Miller has been able to actually photograph sound-waves in the form of a sinuous line on a photograph film. The analysis of such a record gives exact data as to the relative proportions of acoustic energy contained in the fundamental and overtones, and in this way almost every known musical instrument has been studied in the Cleveland laboratories. On receiving an invitation from the writer to undertake a similar study of the sound from the diaphone, Professor Miller kindly agreed to join the party at Father Point and brought with him the "phonodeik", removed for the first time in its history from the laboratory in which it had been constructed and developed. During four days of strenuous efforts on the part of the entire party in overcoming difficulties incident to working with the primitive facilities available at Father Point, a successful series of films was finally obtained at various distances to nearly three miles. These records brought out a number of interesting and important facts: it was found that the sound from a diaphone unprovided with a trumpet was extremely complex; that the effect of a trumpet of correct design was to concentrate a greater proportion of power in the master tone. During propagation through the atmosphere the high overtones do not travel far but are filtered out, the master tone alone surviving to an appreciable extent at distances greater than two miles. It is obvious, then, that overtones produced by the diaphone represent waste of power and that the chief concern of the designer of such apparatus should be to concentrate *all* the energy (if possible) into the master tone. Phonodeik records were also obtained of the sound from a small 2-inch diaphone which could be sounded continuously.

Efficiency tests were also carried out on this small diaphone by the thermal method devised by the writer. The results of 1913 were fully confirmed and this means of rapidly measuring the acoustic cutout of a sound-generating apparatus was reduced to such simplicity that portable apparatus for the use of fog-signal inspectors may easily be designed to carry out such tests. Professor Miller has expressed his conviction that a portable "phonodeik" could be constructed to meet the same requirements. From a thermal test combined with an analysis of a phonodeik record, complete information as to the performance of a fog-alarm may now be obtained. For instance, it is possible to state in horse-power or watts the total acoustic output of a siren as well as to compute the relative proportions of power contained in the master tone and in the overtones. That this may be done as a test is of great importance, as the designer will now be able to predetermine the behaviour of fog-signal apparatus without having the equipment installed at great expense at some station by the sea. It is to be expected that with such methods of testing available, the development and improvement of sirens will be much more rapid than in the past.

To sum up the results achieved by the tests referred to above, it may be stated that methods of measuring sound quantitatively and qualitatively have been developed and tested in practice.

The acoustic characteristics of a siren may now be determined with fair accuracy in absolute measure, whereas previous to these experiments, an almost complete ignorance existed on these points. Measurements of the intensity of the master tone may now be carried out at distances of several miles and the influence of meteorological conditions on the propagation of sound may be studied in the light of accurate data. These achievements conclude an important chapter in practical acoustic engineering. The next step is to bring these results to bear on the improvement of fog-signal machinery. In spite of war conditions, several inquiries from engineering firms and makers of fog-signal apparatus have been received by the writer for information on points connected with the measurement of sound. It is evident, however, that rapid progress in the design of such apparatus can be made only by the organization of a well-equipped experimental station or laboratory under Government auspices. Not only could the actual construction of new sound-generating apparatus be undertaken along lines suggested by the results of tests on existing sirens, but the machines and designs of various makers could be subjected to comparative tests and recommendations made with a view to their amelioration. It has been stated that development of the diaphone in recent years in the matter of power has already led to a noticeable diminution in the annual loss of lives due to fog at points where the more modern types have been installed. There is no reason why further progress should not be made in this direction.

An important field of investigation closely related to that of fog-alarms is the testing of ships' sirens. It is needless to recall the large number of accidents and collisions at sea resulting from failure of pilots to hear acoustic signals even at close range. In fact, the standardization of ship-sirens as to penetrating power and pitch is a question which sooner or later will have to be dealt with by the shipping boards of various countries under international agreement.

It has been proposed to issue fog-signal warnings by submarine acoustic signals, and the results achieved in this direction in the United States lend support to the view that audible signals may be generated more efficiently and will travel with more certainty and to greater distances in water than in air. The attention paid to the development of anti-submarine devices as a result of the war has led to the invention of extremely sensitive receiving microphones. As soon as these achievements in submarine acoustics shall have been made public, their application to navigational problems of all kinds should be undertaken by various government organizations according to some definite program of research. In particular the application of submarine acoustic devices to fog-signal and iceberg problems might well be undertaken in this country as being of special importance to navigation in Canadian waters. In the writer's opinion scientific concentration of these problems with adequate facilities for experimental work at sea would in a few decades more than repay the expenditure incurred, through reduction of the yearly toll in lives and property resulting from accidents at sea.

McGill University,
January 4th, 1918.