POLISH SCIENTISTS PROFILE

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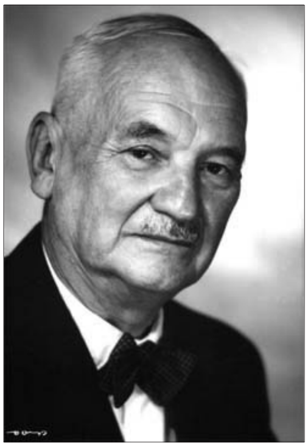
PROFESSOR WOJCIECH RUBINOWICZ'S CONTRIBUTION TO THE DEVELOPMENT OF ACTIVE METHODS OF VIBRATION CONTROL

SUMMARY

World known Polish scientist, physicist Professor Wojciech Rubinowicz (1889–1974) contributed immensely to the development of the theory of active methods of noise reduction. Prof. W. Rubinowicz was dealing mainly with optical phenomena, however it should be emphasised, that light waves and acoustic phenomena can be described by similar theoretical equations. Already in 1917 W. Rubinowicz developed the theory of the edge wave, which later on was named the Rubinowicz Edge Wave. He proved the equivalence of Fresnel's and Young's ideas concerning diffraction phenomena. He developed the mathematical description of the Kirchhoff's diffraction theory. Phenomena of mutual interference of light waves incident on screen edge and the effect in the form of wave compensation in certain zones were described. An incident wave on the screen surface (edge) can compensate itself with the wave of the same structure but phase shifted by π angle, which can cause the total extinction of light. Works of the Polish scientist, which constituted the new approach to the wave phenomena can be considered the starting point in the development of the active method theory.

Keywords: *edge wave, interference, active methods of noise reduction*



WKŁAD PROFESORA WOJCIECHA RUBINOWICZA W ROZWÓJ METOD AKTYWNYCH

Światowej sławy polski naukowiec, fizyk, Profesor Wojciech Rubinowicz (1889–1974) przyczynił się ogromnie do opracowania teorii aktywnych metod redukcji hałasu. Prof. W. Rubinowicz zajmował się głównie zjawiskami optycznymi, jednakże należy podkreślić, że fale światła i zjawiska akustyczne mogą być opisywane przez zbliżone zależności teoretyczne. Już w roku 1917 W. Rubinowicz opracował teorię fali brzegowej, która otrzymała później nazwę teorii fali brzegowej Rubinowicza. Dowiódł równoważności idei Fresnela i Younga dotyczących zjawiska dyfrakcji. Opracował opis matematyczny teorii dyfrakcji Kirchhoffa. Opisał zjawisko wzajemnej interferencji fal światła zachodzącej na krawędzi ekranu oraz efekt kompensacji fal w pewnych obszarach. Fala wypadkowa na płaszczyźnie ekranu (krawędzi) kompensuje się z falą o tej samej strukturze, ale w fazie przesuniętej o kąt π, co powoduje jej całkowite wygaśnięcie. Praca polskiego naukowca, która stanowi nowe podejście do zjawisk falowych, może być rozważana jako punkt wyjściowy w rozwoju teorii metod aktywnych.

Słowa kluczowe: *fala brzegowa, interferencja, metody aktywne redukcji hałasu*

1. INTRODUCTION

The recent twenty years have witnessed a rapid development of active methods of vibration and noise control. Research centers world-wide focus on active methods and the results have left the laboratory stage and new practical applications are being found. Underlying the active vibration control methods is the principle that sounds and vibrations to be reduced are compensated by noise and vibrations from additional sources. Of major importance is the fact that they incorporate an external source of energy. Controlled systems might supply or absorb vibro-acoustic energy in a predetermined manner, from any point of the system (device). The first concepts of active vibration reduction methods appeared in the late 19^{th} century, stemming from the interference theory propounded in 1690 by Christiaan Huygens (1629–1695).

A well-known English researcher Thomas Young (1773–1829) in his work *Course of Lecture on Natural Philosophy* (1807) remarked that „Two identical systems of waves leaving the nearby points will cancel at certain points or reinforce their actions at others" [15]. The basic concepts of noise reduction through the interference of the primary and secondary waves were given by lord Rayleigh (1842–1919). It is worthwhile to mention that the problem utilizing the phenomenon of interference does involve pure interference as in this case interference is achieved for waves propagating in opposite directions, while compensation (reduction) applies occurs in waves moving in the same direction (and hence the terms: "negative interference" and "destructive interference").

The concept suggested by Rayleigh was utilized by a French scholar – Henry Coala in 1932 and by a German Paul Lueg (1933) while developing new patents in the area of active noise reduction.

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Underlying the active methods of sound compensation are theoretical backgrounds provided by M. Jessel. In his works Jessel recalls the effect of concavity, stemming from the well-known Rubinowicz's paradox.

2. PROFESSOR WOJCIECH RUBINOWICZ'S BIOGRAPHY

The outstanding Polish physicist was born in 1889 in Sadagora, near Czernowitz, in the family of a pharmacist Damian and Małgorzata, nee Brodowska. From 1900 to 1908 he attended the German high school in Czernowitz, then moved on to study at the University of Czernowitz, in 1914 he received a Ph.D. degree in mathematical physics. In 1916 he left for Munich, where he worked as Prof. Arnold Sommerfeld's assistant. On returning to Czernowitz he became a *Privatdozent*, having presented the dissertation *Die Beugungswelle in der Kirchhoffschen Theorie der Beugungserchienung*. Invited by Niels Bohr, he went to Copenhagen in 1920, then took an appointment as a professor of theoretical physics in Ljubljana. In 1922 he became a full professor of theoretical physics at the Polytechnic Institute of Lvov.

In the academic year 1935/26 he was the Dean of this Faculty. In the period 1935–37 he worked as the head of the Department of General Mechanics at the Faculty of Engineering of the Polytechnic Institute of Lvov. From 1937 he was a professor of theoretical physics at the John Casimir University of Lvov.

In 1946 he was appointed the head of the Department of Theoretical Mechanics at the Warsaw University. From 1953 he held the position of the head of the Department of Optics and Mechanics, until his retirement. At the same time he also worked in the Institute of Physics of the Polish Academy of Sciences. In 1931 he was elected a member of the Polish Academy of Learning. From 1952 he was a member of the Polish Academy of Sciences.

In the years 1949–1952 and 1961–1974 he was the President of the Polish Society of Physics. Professor Wojciech Rubinowicz was a theoretical physic, his major research interests included quantum theory of radiation, theory of diffraction and mathematical physics.

Professor Wojciech Rubinowicz was a theoretical physicist, his research work focused on quantum theory of radiation, the theory of diffraction and mathematical physics. His outstanding achievements, which made him world famous, included the discovery of rules for quantum transitions in atoms, the theory of electromagnetic quadruple radiation and works on light diffraction. He was the author of a great number of books, including monographs and textbooks.

Wojciech Rubinowicz died in Warsaw in 1974.

3. ANALYSIS OF WAVE MOTION IN THE WORKS OF W. RUBINOWICZ

Professor Rubinowicz's major research interest was the theory of diffraction. In 1917 the work *Die Beugungswelle in der Kirchhoffschen Theorie der Beugungserchienung* appeared, where he transformed the Kirchhoff diffraction integral into what has been known as Rubinowicz representation. The Kirchhoff diffraction theory might be interpreted in two ways. The first interpretation utilises a concept of an edge wave, first proposed by Thomas Young, further developed by Prof. Rubinowicz, who also provided the theoretical backgrounds. The other interpretation involves the Fresnel's diffraction model (Augustin Fresnel 1788–1827), utilising the concept of zones. For a long time that approach was considered to be the only one.

Thomas Young claimed that diffraction occurs as a result of superimposition of a wave propagating in a free space with that appearing in the presence of a screen and hence can be treated as a wave reflected from the diffracting edge. After a while, however, Young abandoned his diffraction model in favour or of the Fresnel's theory of zones. Nearly one hundred years later, Wojciech Rubinowicz showed that the Kirchhoff diffraction field can be divided. Rubinowicz decomposed the Kirchhoff wave into a geometrical –optical wave and a diffraction wave. In his work of 1924 he showed that in the first approximation the diffraction wave might be treated as a wave reflected from the diffraction edge. The starting point for Rubinowicz's work was the Helmholz equation

$$\nabla^2 u + k^2 u = 0 \tag{1}$$

Wave motion was studied in the infinite space containing opaque bodies, referred to as screens. On their surface F the wave function $u(P)$ should satisfy one of the boundary conditions: $u = 0$ or $\delta u/\delta n = 0$. The physical interpretation of boundary conditions is associated with the physical meaning of the wave function. If the function $u(P)$ is a velocity potential, then $\mathbf{v} = \text{grad}\, u(P)$ denotes velocity and $\mathbf{n}\, \text{grad}_P\, u(P) = \delta u/\delta n = 0$ indicates that the normal velocity component disappears and hence the screen surface should be immobile. In acoustics, such screens are referred to as "hard". In the case of the boundary condition, when $u(P) = 0$ the screen is called "soft". On the surface of such screens the acoustic pressure tends to disappear. Let us consider an incident wave radiated by an isotropic and point light source L (Fig. 1).

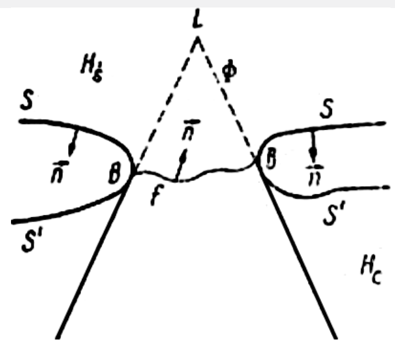

Fig. 1. A rough sketch for Rubinowicz's analysis [12]

For this specific case we get

$$u(P) = \frac{e^{ikr_{LP}}}{r_{LP}} \tag{2}$$

Let us assume that the screen has only one aperture and beyond that it will stretch to infinity. Accordingly, the half-lines originating in the light source and tangent to the screen surface F should form a half-cone Φ.

A wave field in infinity consists exclusively of waves incoming from finite regions, it satisfies Sommerfeld's condition of finity and radiation. Imprecisely formulated conditions are referred to as Helmholz boundary problems. For a point source, the solution to this problem is given by Green's function in space in which the diffraction problem is defined. Kirchhoff claimed that an approximate solution is obtained when approximated boundary values are inserted in the Helmholz-Huygens rule. It turned out later that what is solved this way are step problems.

The curve of points of a half-cone Φ from the screen surface F is referred to as the diffracting edge and designated by B. The portion of the half-cone Φ from the edge B to infinity is called the shade boundary.

The diffracting edge B divides the screen surface in two parts:
1) S – lit surface,
2) S' – unlit surface (in shade).

The concepts of a shade half-space H_C and light half-space $H_{\dot{S}}$ are introduced. The analysis of the problem would finally yield the solution known as Kirchhoff integral. Rubinowicz proved that under certain assumptions Kirchhoff integrals become the solutions to step problems and that step quantities are determined by an incident wave.

Kirchhoff described the screen in the diffraction theory as black. The screen referred to as Kirchhoff screen absorbs only incident waves and is transparent to diffraction waves. Generally speaking, only flat screens can be regarded as black as they satisfy the two conditions:
1) each half-line originating at the light source should once intersect the screen S such that light should not pass through the screen more than once;
2) elementary waves emanating in various points of the diffraction edge are not able to pass through the screen, so the screen need not be regarded as transparent to diffraction waves.

A German physicist Max von Laue observed that the reciprocity principle applies while swapping the light source L and detection point P in the case of wave motion determined by the Kirchhoff integral [17]. Laue formulated this theorem for an detection point P located in the shade half-space H_C. In 1961 Rubinowicz generalised the reciprocity formula, to incorporate the cases where the detection point is located in the lit half-space $H_{\dot{S}}$.

4. STATUS OF PROFESSOR W. RUBINOWICZ'S CONTRIBUTION

An American Eugen Skudrzyk – a well-known specialist in acoustics in his work *Fundamentals of Acoustics* wrote the chapter 24: "Huygen's Principle and Rubinowicz–Kirchhoff Theory of Distribution," mentioning Prof. Rubinowicz's achievements that contributed to the further developments in acoustics.

Let us consider the analysis performed by W. Rubinowicz and then quoted by Skudrzyk. The analysis of Huygens integral reveals that the total area comprises two distinct parts:
1) geometric –optical,
2) diffraction fields.

The conclusion is drawn that the Kirchhoff integral can be decomposed in two elements. The decomposition procedure is as follows. Let K stand for the surface dividing the light from shade. This surface comprises all shade points and a part of a conical surface determined by rays emanating from the source L, passing through the screen edge and forming the shade boundary (Fig. 2). The designations are as follows: A – surface area of an aperture in the screen; d_s – edge element; P – detection point; Q – a point on a ray.

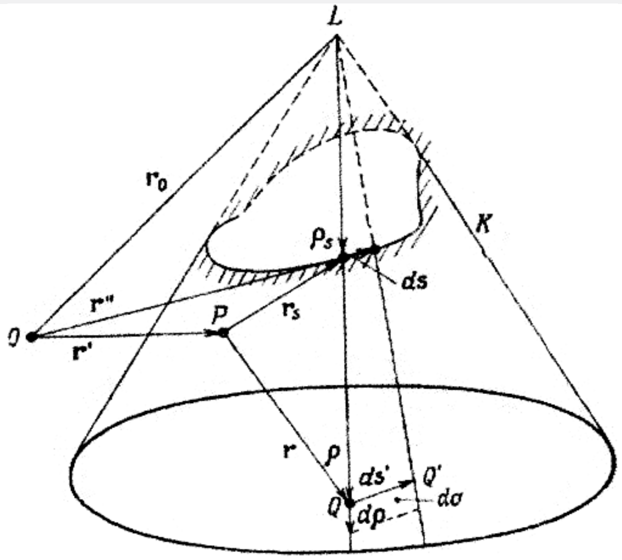

Fig. 2. A sketch by W. Rubinowicz

Rubinowicz defined the velocity potential by analysing the Kirchhoff integral. This potential is given by a formula

$$\Phi = \alpha\,\Phi_g + 1/4\pi \oint A ds \qquad (3)$$

where:

$\alpha = 1$ – inside the light cone,
$\alpha = 0$ – beyond the light cone, in the geometric region of shade,
Φ_g – potential of geometric-optic part of the area.

Leaving aside the mathematical description, we assume the existence of opaque bodies, referred to as screens. In acoustics the distinction is made between hard screens (if Φ is velocity potential, the normal velocity component will disappear and the screen surface remains immobile) and soft screens (when velocity potentials are zero and acoustic pressure is zero). Rubinowicz reached the conclusion that wave motions on the lit and shaded side of the screen should differ only in the behaviour of the incident wave. The screen absorbs the incident wave, remaining opaque to all other waves as it remains unchanged by deformations. Of particular importance was that part of the screen that swould be shaded on the lit side because of wave-like shape of the diffracting screen. The screen can be deformed in any way whilst diffraction phenomena will not change. Such screen is called a "wavy" screen or Kirchhoff wavy screen. Rubinowicz observed step-like motion of a wave that on a wavy screen. The proposed interpretation is that such screens absorb incident waves. In the case of a screen formed by an arbitrary surface, it may happen that light rays, i.e. half-lines originating from the source should pass through the screen twice or even more times. Thus the behaviour of incident light on the Kirchhoff screen seems paradoxical. This phenomenon is known as Rubinowicz's paradox. M. Jessel, one of the researchers who provided theoretical backgrounds of active methods of noise reduction, states in his works [6, 7] that the concavity effect originates from Rubinowicz's paradox. While analysing the area in which an acoustic field occurs, one part of this field supports the Huygen's source conformity, while the other supports the active source reduction. Rubinowicz predicted this effect on a Kirchhoff's screen.

5. SUMMING UP

Kirchhoff's theory of diffraction was studied theoretically by Wojciech Rubinowicz. The founders of active methods of noise reduction utilised the achievements of this outstanding Polish scholar who focused chiefly on optical phenomena, not on acoustics. Both optical and acoustic effects are wave-like phenomena governed by similar equations, that is why the works by this Polish scholar who started the new approach to the studies of waves might be regarded as the starting point, as theoretical backgrounds underlying the active methods. Unfortunately, major achievements of Polish scholars and their contribution to research achievements world-wide tend to be forgotten. Many authors specialising in active methods do not know the works of Prof. Wojciech Rubinowicz, and his works are rarely quoted. The main purpose of this paper is to recall the research achievements of Prof. Rubinowicz and his contribution to the development of active methods.

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