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Vibration Reduction of a Simply Supported Beam with Electromagnetic Actuator

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ABSTRACT

Structural vibration is one of the major problems in the field of structural engineering. The vibration of structures can be minimized in two ways namely passive vibration control and active vibration control. Passive vibration control doesn't depend upon the output of the system. Generally springs, viscous dampers etc. are used for reducing the amplitude of vibration. Active vibration control depends upon the output of the system. In this study an attempt will be made to minimize the amplitude of vibration of simply supported beam structure using active vibration control method. For this purpose magnetic actuator is used to minimize the amplitude off vibration. An electromagnetic actuator will be used to apply the electromagnetic actuating force. The electromagnetic actuating force will be applied in opposite phase of the displacement of the structure. In this study an attempt will be made to apply such non-contact actuating force to minimize vibration of structure. This non-contact force is important because it will not damage the structure. The electromagnet is placed below the beam structure at mid span position. The constant dc current is passed through coil of electromagnet to generate electromagnetic actuating force which is applied on the beam and in the direction opposite to the exciting force. A simply supported beam is considered in this study and its equation of vibration is expressed in state space model in MATLAB Simulink environment. The single degree of freedom model of the beam is considered in this study. The first natural frequency of the beam as well as mode shape of the structure will be calculated. A disturbing force is applied on the beam at the mid span of the beam. The concentrated force whose frequency is changing with time is applied in such a manner that the natural frequency of the beam lies in the range of the frequencies of the exciting force. Due to the application of this force, resonance is observed when the frequency of the exciting force matches with the natural frequency of the beam. The electromagnetic actuating force is applied on the beam to minimize its amplitude of vibration. The electromagnetic force is applied only during the upward movement of the beam. During the downward movement of the beam the electromagnet is switched off and no actuating force is applied on the beam. It is shown in his study that the proposed actuator is successfully minimizing the amplitude of vibration even at the resonance also.

KEYWORDS

Vibration, actuator, electromagnet, natural frequency, displacement, sensors.

INTRODUCTION

The structures that are seen in everyday life are always exposed to some kind of external force or wearing agent such as any impact force or a jerk or sometimes maybe even the load it is supposed to lift or carry and which results in the deformation or breaking of the structure. The vibration that is observed is basically the constant to and fro motion of the body about its fixed static position when provide any exciting force. The magnitude of the vibration causing force may vary from time to time, place to place, situation to situation or perhaps even on the type of body being considered in the environment. The force may be one which acts like a sine wave or maybe which comes from two different directions time to time or maybe even a force that has a periodically changing magnitude to itself. The frequency even at which the force comes may even vary or remain constant.

Mechanical systems used in everyday life or any body having some mass experience vibration in it sometime or the other. It is a natural phenomenon or sometimes forced and has both useful and harmful effects. The damage done by mechanical vibration to different structures and machines was observed and understood as discussed in the article on impact of vibrations by Krehel et al in the year 2016. The increase in vibration and its effect on the splinter of a lathe machine was studied and frequency analysis was done[2].

The magnitude of the force may be small or equal to weigh of the body or a large load that begins to act on the body. The control of this vibration can be done in two ways that is active vibration control or passive vibration control. These methods were realized from the article on vibration control of systems by Barcik et al in the year 1998. They have shown the different kinds of problems due to vibrations and techniques to control it using dampers[7]. The methods of passive vibration control make use of spring or viscous dampers or stuff which are kind of added so as to absorb the vibration of the body. It does not depend on the magnitude of the exciting force but is expected to act as per the specification of the damper itself. It is basically to reduce the displacement range of the structure in consideration. Such kind of helping accessories can be thought of as shock absorbers that merely help to prevent any serious breaking of the body in consideration.

Here for the experiments, a simply supported beam was considered for analysis. The method that is being discussed here is the active vibration control method in which a counter force to the initial force will be applied so as to reduce vibration in a simply supported beam. An electromagnetic actuator will be designed in a manner such that the actuator will carry a current just under the beam and the electrostatic force that acts on the beam will try hold the beam in static position from the input force. The actuator will reduce the displacement periodically and act as per its natural frequency as experimentally verified by Huang in his article on periodic vibration absorber in 2014. He found out the significance of the frequency of the vibration of any body and its effect while reducing it[3].

MATHEMATICAL MODELLING

A simply supported beam was defined in MatLab software. The beam was considered to be a single degree of freedom system and the equations that were used to define the beam are similar to the ones used to define a simple spring mass damper system. For a body of mass 'm', attached to a spring of stiffness 'k', a damper of damping coefficient 'c' and an external force of magnitude 'F' is acting on the system the relation between the displacement x, velocity x and acceleration x is given by

$$\ddot{x} = -\frac{c}{m}\dot{x} - \frac{k}{m}x + \frac{F}{m} \quad (1)$$

This simple differential equation of second order can be reduced to the matrix form by using the formula

$$\begin{Bmatrix} \ddot{x} \\ \dot{x} \end{Bmatrix} = \begin{bmatrix} -\frac{c}{m} & -\frac{k}{m} \\ 1 & 0 \end{bmatrix} * \begin{Bmatrix} \dot{x} \\ x \end{Bmatrix} + \begin{bmatrix} \frac{1}{m} & -\frac{1}{m} \\ 0 & 0 \end{bmatrix} * \begin{Bmatrix} F \\ 0 \end{Bmatrix} \quad (2)$$

$$\begin{Bmatrix} \dot{x} \\ x \end{Bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} * \begin{Bmatrix} \dot{x} \\ x \end{Bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix} * \begin{Bmatrix} F \\ 0 \end{Bmatrix} \quad (3)$$

This representation of the equation into two matrices helps in inserting the respective values into the state space block in Simulink. The above equation helps in determining the value of the acceleration of the block. The next equation is an auxiliary equation that is used to balance the matrices to be defined in the state space. The above equation can be seen synonymous to the type of equation a state space block has which makes it easier to feed data.

SIMULINK MODEL

A simulink model was created in a MatLab simulink environment so as to find the displacement and velocity of a simply supported beam being acted upon by a force and hence try to determine a method to reduce the displacement of the body.

The model created consists of the beam that was mathematically defined, the electromagnet and a switch to stop and operate the flow of current. This model makes it easier to visualize the possible outcomes of the input parameters that can be provided to the system under consideration. It is also very useful in arranging all the elements that are required to design the actuator.

The model is indeed a very helpful arrangement to find the current in electromagnet as it almost resembles a real life experimental setup with all the natural forces and elements under

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consideration. The mathematical expressions of the beam executing single degree of freedom motion gives accurate results calculating according to the input forces provided to it. We can say it is almost like visualizing the whole experimental setup in a schematic manner (Figure 1).

NUMERICAL ANALYSIS

A simply supported beam was considered of length 70 cm and its cross section was considered to be 26mm by 6 mm. This was done so as to help visualize the beam

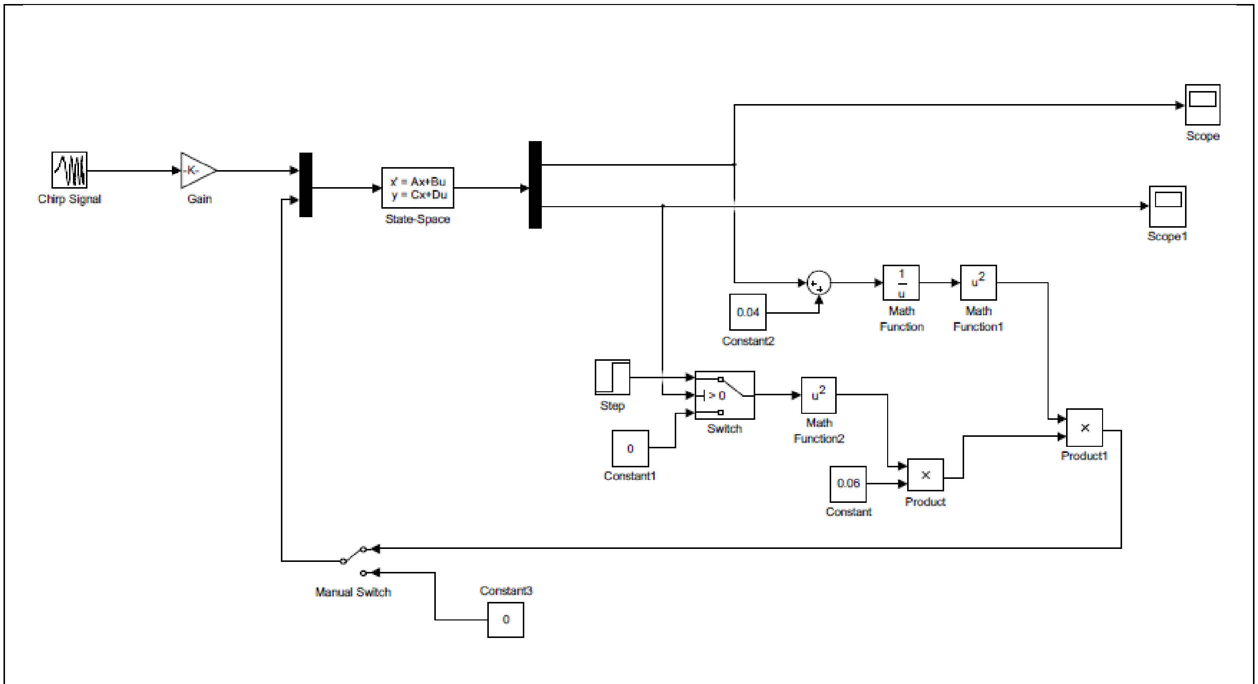

Figure 1. Simulation Model for Beam and Actuator.

properly and try find out its physical proper ties. Its area moment of inertia was found out using the mathematical formula

$$I = \frac{1}{12}\,\text{breadth} * (\text{height})^3$$

This came out to be 8.4×10^{-6} m^4

The material of the beam considered was mild steel. The density of mild steel is 7.85g/cm^3 and the Young's modulus of elasticity of mild steel is almost 200 G Pa which gives the stiffness of the beam as

$$k = 48\,\frac{E*I}{l^3} \qquad (4)$$

So the stiffness comes to be 2486490 N/m

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And the natural frequency so calculated was

$$\omega_n = \frac{1}{2\pi}\sqrt{\frac{k}{m}} = 20 \text{ Hz.}$$

An input excitation force of variable frequency was given to the beam. It was fixed that the initial frequency will be 10 Hz and the final frequency to reach would be 30 Hz. The time span for which this experiment would be conducted will be 10 sec (Table 1).

The actuator to be designed is a small coil of wire placed just below the beam. The wire will be placed at 5 cm below the beam.

The current in the actuator will be a dc current that will be passed. The current in the wire will be connected to a knob or a switch such that it can be put on and off as per our need and timing (Table 3).

Moreover the source of the current will be such that the magnitude of the current could be changed manually as per the wish of the operator.

The first set of experiment was done without any actuating force to observe the first mode shape of the beam when the excitation force would reach the natural frequency of the beam. A displacement sensor would show the readings of the displacement of the beam

Table 1. Excitation Force Parameters

S.No.	Initial Frequency (Hz)	Time (sec)	Final Frequency (Hz)	Magnitude (N)
01.	10	10	30	100

and a vibrometer would give the velocity readings. In this case a displacement vs. time curve and a velocity vs. time curve were plotted in the simulation model to give a clearer picture of what the shape of first harmonic of the beam looks like(Table 1)

The state space was defined such that it gives the velocity and acceleration of the beam. A is $\begin{matrix} -50 & -246489 \\ 1 & 0 \end{matrix}$ (Table 2).

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Table 2. Initial Displacement of Beam

S. No.	Time (sec)	Mode shape	Maximum Displacement (10^{-2} m)
01	10	1^{st} mode	3

Table 3. Location of Actuator

S. No.	Permittivity Constant (Nm^2/A^2)	Gap Between Beam (m)
01	0.06	0.05

The next part of the experiment deals with the current in the actuator being switched 'on' and the magnet applying the opposing force on the beam so as to reduce the vibration. The values of the current are to be determined in his situation. The electromagnet has the wire wrapped around it in a coiled manner. The permittivity of the magnet in this kind of setup is approximately 0.06 Nm^2/A^2

Here onwards an attempt was made to apply the electromagnetic force on the beam when it would display an upward motion. In simple words, when the beam would be going up it would try to bring the beam down by the magnetic force of attraction having being paced below the beam. But when it would be coming down the actuating force would no longer be required and hence it would be put off automatically. This is because of the fact that current in use is a dc current and that this kind of current will surely give only one polarity to the magnet in use.

So we introduce a filter or a check switch in our model which will verify whether the beam is going up or coming down. The vibrometer can give the velocity readings of the beam once it starts vibrating. This would initiate the current to flow and the electromagnet put into action. The filter would be so defined as to put the switch on only when the velocity is positive or going up. The threshold was defined as 0. This was to give the force when beam is going up. When the beam is moving downwards there will be no force from magnet, i.e. 0 output current in the wire.

The power source of current is also being provided with a knob so as to change the magnitude of current. The switch was put on

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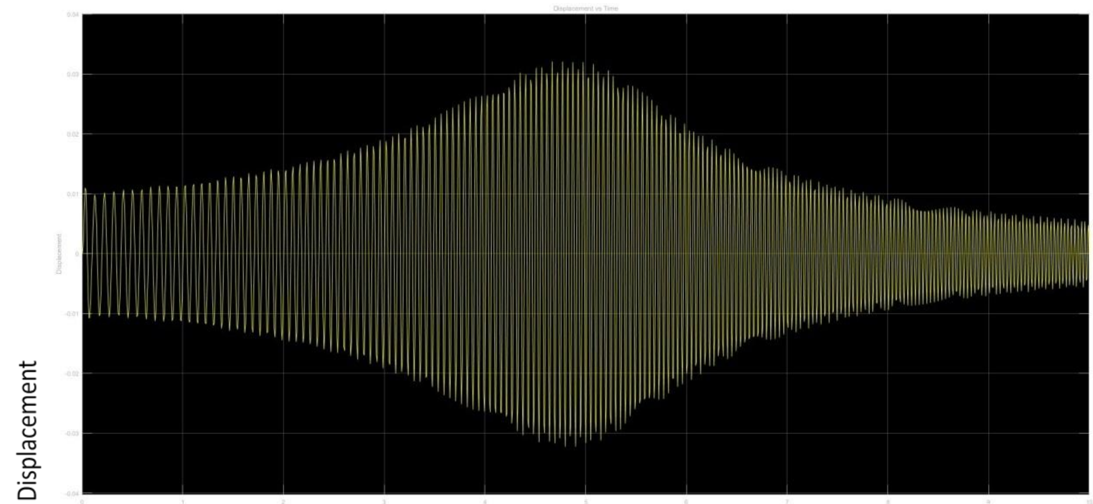

Figure 2. Displacement vs Time curve with switch off

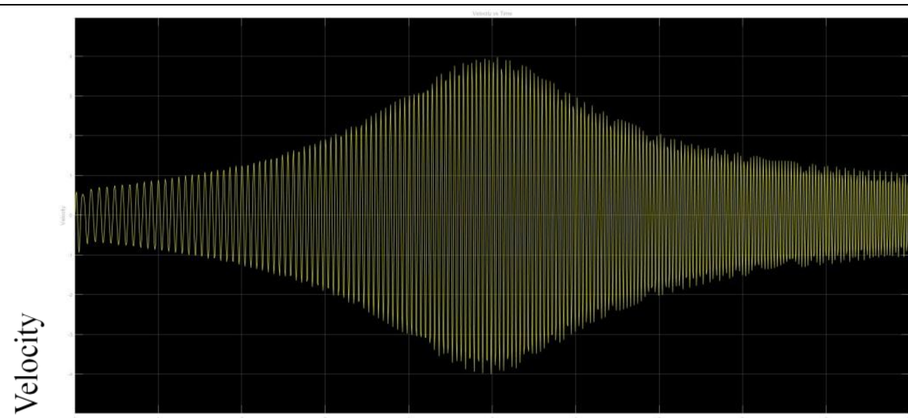

Figure 3. Velocity vs Time curve with switch off

and the current required for the above setup and problem in consideration was found out.

RESULTS

The experiment to reduce the vibration of the beam came to its most favorable position when the beam would show minimum possible displacement from its mean position.

The current values determined were an initial current of 0.6 Amp for 1.5 sec and hence forth a current of 1.8 Amp (Table 4).

Table 4. Current in Actuator

S.No.	Initial Current (Amp)	Time (sec)	Final Current (Amp)
01	0.6	1.5	1.8

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difference between the displacement and velocity values when the magnetic force came into action. The reduction in the displacement was calculated and the efficiency of the Simulink model was calculated showing a good 83 % efficiency was observed in reducing the beam displacement (Table 5). The curve was sooth curve with no real rise suddenly in the movement and the maximum and minimum were reduced to almost a uniform value.

Table 5. Result & Efficiency

S. No.	Displacement (cm)		Difference (cm)	Efficiency (%)
	Initial	Final		
01	3	0.5	2.5	83

Finally this model was proving to be useful in the manner it was intended. The current was not wasted and the filer was doing its job well. The step input was proving to be the most useful during this time and so was with the case with how efficiently it can be tackled.

The application of force in only one phase of motion can be understood in a manner that we don't wish to apply a force along with the excitation force but rather in opposite direction to the force.

CONCLUSIONS

Finally it can be concluded from the above observations that the electromagnetic actuator can be a very useful tool that can be used to safe guard the everyday mechanical structures we see around us. It is quite effective in its work and is useful in the sense that the current can be controlled as per the requirement and the beam (Figure 4).

It is worth commenting that the beam in consideration was a single degree of freedom system and is not always applicable to a few complex real life situations. However by looking into the problem and the fundamental design it is useful model as how the system behaves and its uses it the simple machines and structures we find(Figure 5).

The current that was supplied was a dc current as it is easy to supply and control. Here an ac current find itself tough o control because a sudden mismatch of phase of magnet and beam motion would result in counterproductive results. Also the ac available is fixed in its frequency, whereas the dc frequency is simply related and in

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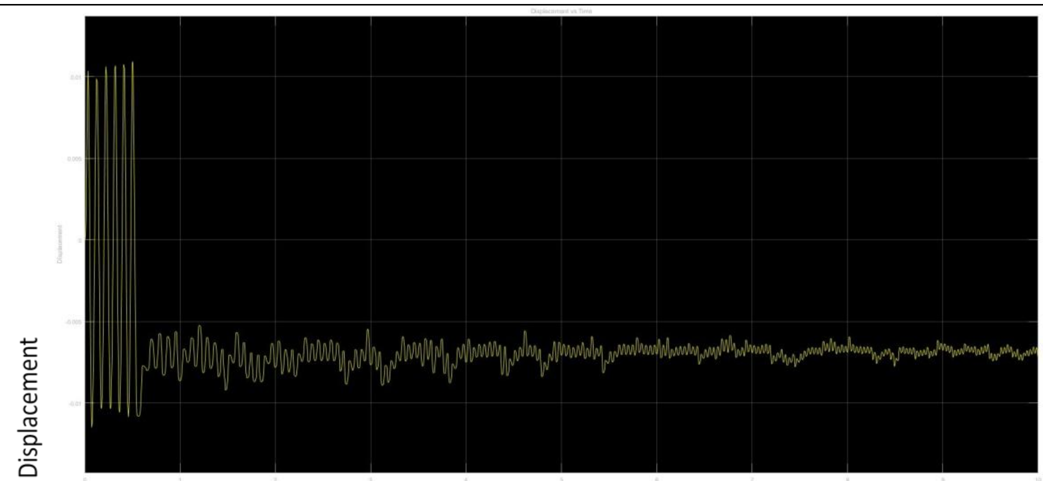

Figure 4. Displacement vs Time curve with switch on

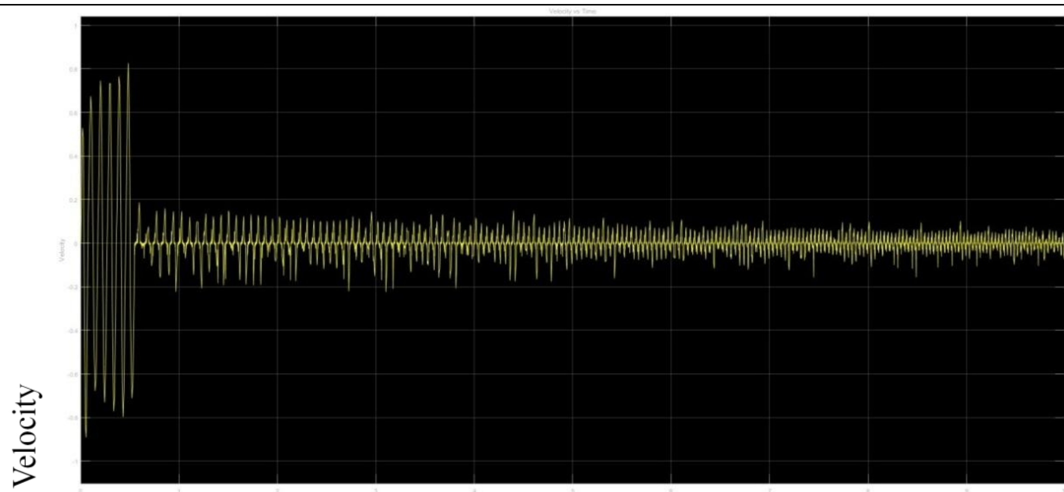

Figure 5. Velocity vs Time curve with switch on

correspondence to the frequency of the beam.

The gap between the beam and magnet is kept at a reasonable distance possible as per the convenience of the model. But it can be changed if demand arises.

This model is also applicable to various different vibration causing sources too.

REFERENCES

[1]Viabhav Ghodgi, A .P. Bhattu, S. B. Patil, "Vibration analysis of beams" , International Journal of engineering trends and technology, volume 55 number 2, Page 81-86, 2018

ISSN: 2005-4238 IJAST

[2]Radoslav Krehel, Martin Pollak and Marek Kocisko, "Research on impact of mechanical vibration on the production machine", Advance in mechanical engineering volume 8(7)1-10,2016.

[3]Shyh-chin Huang and Kao-an Lin, " A new design of vibration absorber for periodic excitation", Hindawi publishing corporation shock and vibration, volume 2014,article ID 571421, 1-11, 2014

[4]Vogneshwaran K., Behra R.K., "Vibration analysis of simply supported beam with multiple breathing cracks", 1st International conference on Structural integrity, ICONS-2014, 835-842

[5] Irshad A. khan, Dayal R.P., "Finite element Analysis of Double Cracked beam and its Experimental validation" procedia engineering, volume 51, pages 703-708, 2013

[6] SS Rao, "Chapter 9, vibration control", Mechanical Vibration, volume 5, 819-830,2009

[7] Monika Barcik, Jaroslaw Koneczny, Janusz Kowal and Bogdan Sapinski, "Vibration control of mechanical systems-introduction to the problem", Acta montanistica slovaca, Rocnk 3,504-509,1998.

[8]Watanabe T., "forced vibration of continuous system with non linear boundary conditions" J.Mech design, ASME, 487-491, July 1978

[9] Panda A, Prislupcˇa´k M, Jurko J, et al. Vibration and experimental comparison of machining process. Key Eng Mat 2016; 669: 179–186.

[10] O´ kiewski S. Damped vibrations problem of beams fixed on the rotational disk. Int J Bifurcat Chaos 2011; 21: 3033–3041.

[11] Moussa WA and Abdelhamid AN. On the evaluation of dynamic stresses in pipelines using limited vibration measurements and FEA in the frequency domain. J Press Vess: T ASME 1999; 121: 241–245.

[12] J. P. denHartog,*MechanicalVibration*,McGraw-Hill,NewYork, NY, USA, 1934.

M. Z. Ren, "A variant design of the dynamic vibration absorber," *Journal of Sound and Vibration*, vol. 245, no. 4, pp. 762–770, 2001.

[13] R. E. D. Bishop and D. C. Johnson, *The Mechanics of Vibration*, Cambridge University Press, Cambridge, UK, 1960.