X10 (R-295)

NAVY DEPARTMENT
DAVID TAYLOR MODEL BASIN
WASHINGTON, D.C.

MEASUREMENTS OF STRAIN IN THE RADIAL WEBS OF THE BASE RING OF THE MARK-37 GUN DIRECTOR

by

E. Wenk, Jr.

DECLASSIFIED

~~RESTRICTED~~

January 1946

Report R-295

PERSONNEL

The tests were conducted by E. Wenk, Jr., assisted by W.A. Lovell and Ensign R.L. Davies, USNR, of the David Taylor Model Basin. Results of the tests were analyzed by Margaret E. Duke and Mr. Wenk. The method of correcting the strain records as outlined in the Appendix was suggested by Lieut. Comdr. D. Bancroft, USNR.

MEASUREMENTS OF STRAIN IN THE RADIAL WEBS OF THE BASE RING OF THE MARK-37 GUN DIRECTOR

ABSTRACT

When cracks were discovered in the radial webs of the base rings of new Mark-37 gun directors, representatives of the Naval Gun Factory suggested that the defective material be removed from the webs before the rings were put in service. The safety of this procedure was determined from the estimate of stresses in the reduced webs, based on strains measured on the full webs during the structural firing trials of the USS ALASKA (CB1). The strain measurements and an interpretation of results are given in this report.

Strains were measured with metalectric gages in groups of three, each group mounted on the web in a rosette pattern. The strains which occurred simultaneously with a peak strain in any of the three gages of the rosette were employed to calculate the principal stresses and the maximum shear stresses. The maximum principal stress was 1800 pounds per square inch, and the maximum shear stress was 1050 pounds per square inch. Where the available data were insufficient for a complete rosette analysis, the observed peak strains were multiplied by an assumed modulus of 30 million pounds per square inch to obtain a value for the stress that would have existed at that gage station if the stress had been uniaxial and in the direction of the axis of the gage. The maximum calculated stress was 2700 pounds per square inch.

These measurements indicated that the service stresses in the full webs were very low so that the radial webs could be reduced in size without serious impairment to the strength of the ring. Complete elimination of the webs was not recommended.

INTRODUCTION

The firing of dual-purpose 5-inch 38-caliber guns has generally been controlled on U.S. Naval vessels of all categories by the Mark-37 gun director. This director rotates on groups of horizontal and vertical rollers supported by a cast-steel base ring that serves as a lower roller track. The casting is hollow and has an irregular cross section, as shown in Figure 1a, with a projection that engages the holding-down clips of the director; it is stiffened by radial webs at intervals of 15 degrees.

Cracks in the radial webs of some of the base rings were discovered after casting, and to prevent the extension of these cracks in service, representatives of the Naval Gun Factory suggested (1)* that the defective

---

* Numbers in parentheses indicate references on page 9 of this report.

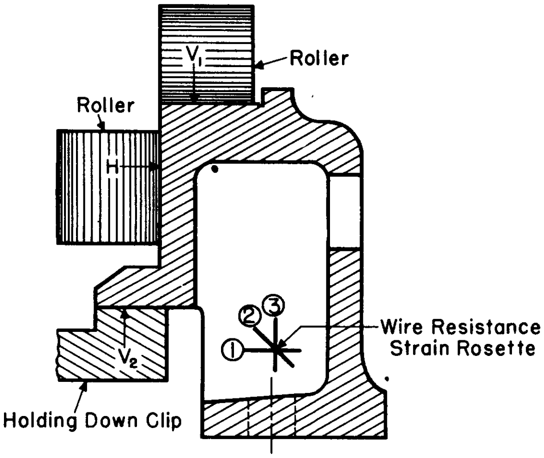


Figure 1a - Radial Section of Ring

The forces H, V_1, and V_2 are produced by the overturning moment of the gun director, which results from the blast and inertia effects of the firing of the gun.

material be removed from the webs. The finish machining had been completed on the cracked rings, and operations other than partial removal of the webs would have been inadvisable because of the warping that might result. It was therefore considered essential to investigate the strength of the base rings after portions of the webs had been removed. A theoretical analysis of stresses in the webs would be difficult to derive since the magnitude and distribution of service loads were unknown. If the stresses in the full webs were determined, however, it would be possible to estimate those in reduced webs. Therefore, the Bureau of Ordnance requested (2) that the David Taylor Model Basin conduct tests of an installation now in service to measure stresses in the full webs of a base ring of a Mark-37 director when it was subjected to loads resulting from blast and inertia effects of the director during actual gun firing.

The first ship with a heavy main battery that was available for such tests was the USS ALASKA (CB1), and the tests were made during the structural firing trials on 9 August 1944. The results are given in this report.

TEST SETUP AND PROCEDURE

Two Mark-37 gun directors are used on the USS ALASKA to direct the fire of the secondary battery, one forward and one aft. The forward director was selected for the test since it would be more exposed than the after one to the blast from firing of guns of her main battery.*

Strains were measured in three of the radial webs that were expected to be the most highly stressed at some time during the structural firing trials. The locations of the gages are shown in Figure 1.

---

* The main battery is composed of nine 12-inch 50-caliber guns disposed in three triple-gun turrets, two of which are forward of the control tower and the third one abaft the superstructure.

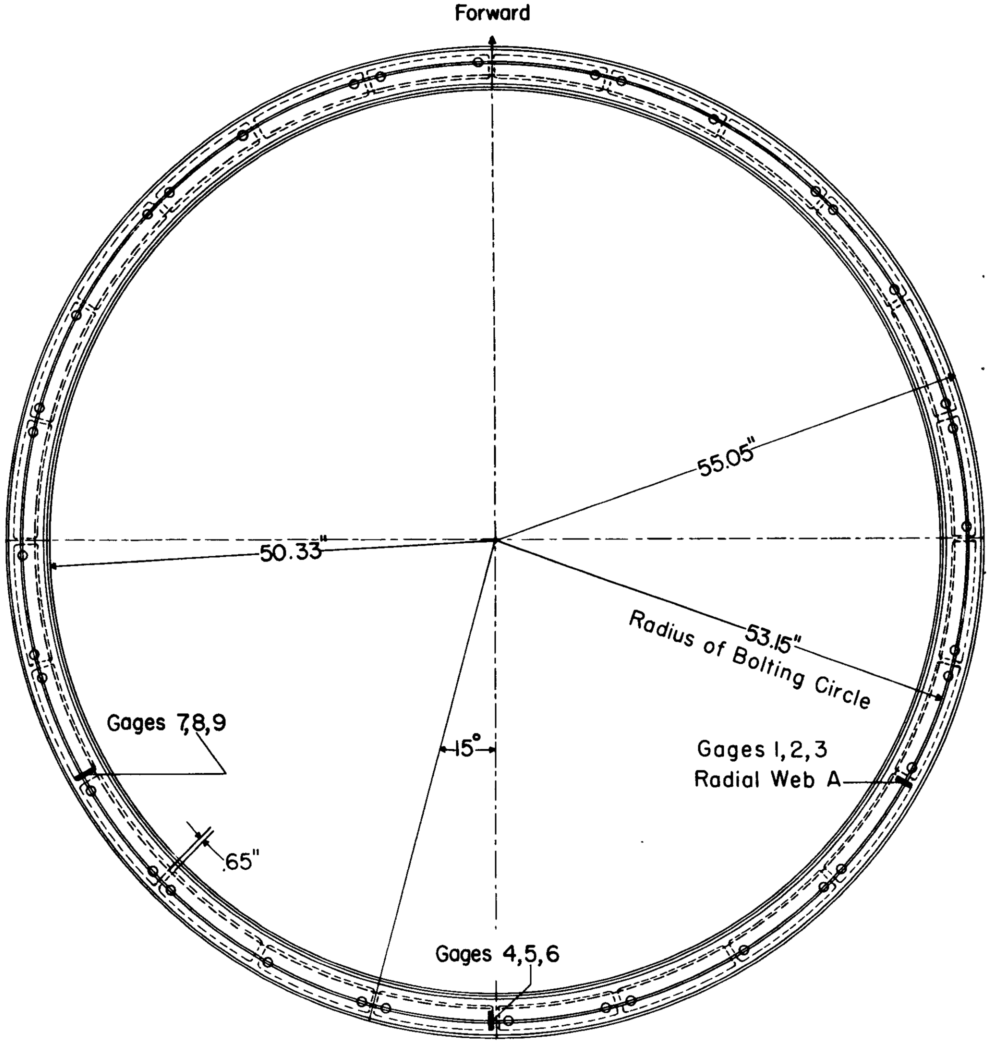


Figure 1b - Plan View of Ring

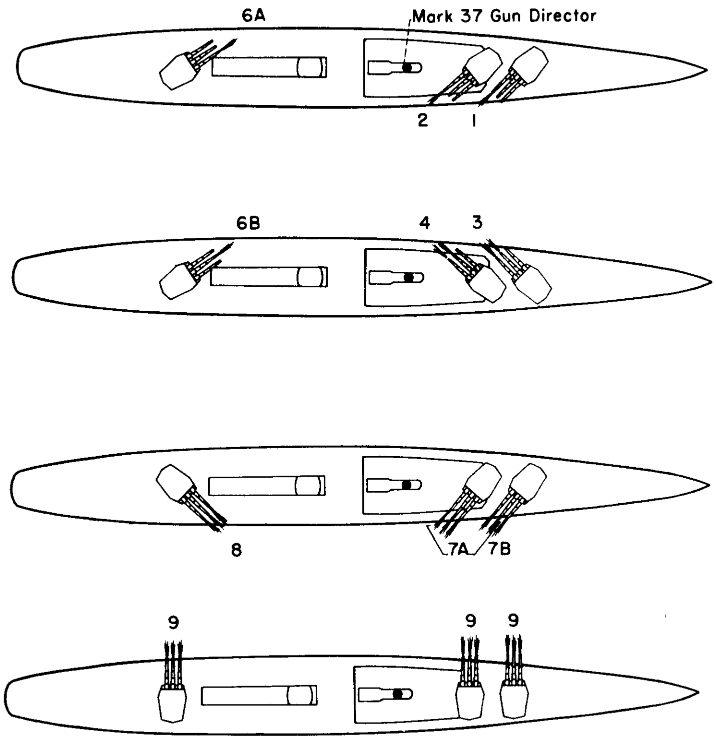
Figure 1 - Sketch of Base Ring, Showing Location of Strain Gages and Direction of Forces

Strains were measured at three stations on the base ring, as shown in Figure 1b. The gages were arranged on the webs in rosettes, as in Figure 1a. Gages 1, 4, and 7; Gages 2, 5, and 8; and Gages 3, 6, and 9 occupied corresponding positions in their respective rosettes. Data were not obtained from Gage 9 because of lack of recording equipment.

Metalectric strain gages having a base length of 1 inch were employed in the test, arranged in groups of three on each selected web in a 45-degree rosette pattern.* The orientations of the rosettes are given in Figure 1. Each gage of the rosette was connected in a conventional direct-current Wheatstone bridge circuit so that any variation of strain which changed the

---

* Baldwin-Southwark rosettes, Type R-2, were used in the test.



Salvo	Turret	Gun	Train degrees	Elevation degrees	Distance from Director to Nearest Gun Muzzle feet
1	1	R	135	20	115
2	2	R	140	20	60
3	1	C and L	225	20	115
4	2	C and L	220	20	60
6A	3	R	325	20	215
6B	3	C	325	20	215
7A	1 and 2	RC - 1; all - 2	130	40	60
7B	1	L	130	40	125
8	3	All	45	40	215
9	1, 2, 3	All	270	0	100

Figure 2 - Train and Elevation of Guns during Structural Firing Trials of Main Battery, USS Alaska (CB1)

resistance of the gage also produced an unbalance of the bridge. This unbalance, in the form of a change in voltage, was amplified by vacuum tubes and was recorded on sensitized paper by a string oscillograph.

Strains were recorded during each salvo of the main battery. For the most part, guns were trained and elevated so as to produce the greatest blast effect on the ship structure. In all salvos, the train of the director was the same as that of the turret being fired. The spatial relationship of the guns to the director is shown for all salvos in Figure 2.

TEST RESULTS

The observed peak strains for each gage are presented in Table 1, together with the interval of time from the estimated instant of firing to the occurrence of the peak.

The product of E* times strain gives the stress that would have existed at that gage if the stress had been uniaxial and in the direction of the axis of the gage. The stress calculated in this manner from the maximum observed strain was 2700 pounds per square inch. It occurred at Station 8 during Salvo 7A.

The principal stresses, the shear stresses, and the orientation of axes of major principal stress have been calculated** where sufficient data from strain rosettes were available. The results are given in Table 2. Only data from the radial web A could be analyzed. The maximum principal stress was found to be 1900 pounds per square inch in Salvo 7A. The maximum shear stress was found to be 1100 pounds per square inch in Salvo 7A.

Various frequencies of the cyclic variation of strain were identifiable on the records, and are given for various salvos in Table 1. The predominant frequencies were 4.2, 11, 15, 30, and 55 cycles per second.

ANALYSIS OF RESULTS

The strains were determined from amplitudes of the recorded signals by comparing the records with a calibration curve made immediately before the test. The calibration curve was obtained by applying to the recording system a signal† whose magnitude corresponded to a strain of 86.2 microinches per inch. Whereas this method of deriving the strains was quite accurate, some

---

* The modulus of elasticity E was assumed to be 30 million pounds per square inch.

** This information was obtained by means of a graphical solution of strain-rosette data (3). No corrections were made for the effect of strain in the direction of the transverse wire in the metalectric gages.

† The signal was in the form of a step pulse, that is, a pulse rising instantaneously to a specified value and remaining constant thereafter. The pulse was created by switching a fixed resistor in parallel with the gage so as to change the effective resistance of the gage by an amount corresponding to a selected strain.

TABLE 1

Peak Strains Measured on Radial Webs

Salvo	Gage	First Peak		Second Peak		Third Peak		Observed Frequencies cycles per second
		Strain microinches per inch	Time from Instant of Firing seconds	Strain microinches per inch	Time from Instant of Firing seconds	Strain microinches per inch	Time from Instant of Firing seconds	
1	1	-12	0.04	-12	0.09	-12	0.13	55
	2	-32	0.04	-29	0.09	-15	0.13	13, 55
	3	-14	0.04	-14	0.09	-17	0.13	13, 55
	4	0		-11	0.10			
	5	-10	0.04	-13	0.10			
	6	0		0		0		
	7	-12	0.04	+13	0.08			14, 55
	8	-35	0.04	+39	0.08			14, 55
2	1	0	0.02	+17	0.06	0	0.17	13, 55
	2	-42	0.02	-27	0.06	+41	0.17	13, 55
	3	-17	0.02	-39	0.06	+36	0.17	13, 55
	4	-20	0.07	+25	0.14			11
	5	-24	0.07	+46	0.14			11
	7	-23	0.05	+ 7	0.13	-53	0.16	
	8	+53	0.05	+49	0.13	-70	0.16	35
3	1	+ 4	0.03	+ 4	0.05	- 4	0.08	55
	2	-22	0.03	+19	0.05	-26	0.08	15, 55
	3	-19	0.03	+19	0.05	-17	0.08	55
	4	-13	0.06	+10	0.09	-15	0.18	15
	5	-26	0.06	+23	0.09	-17	0.18	15
	6	0		0				
	7	+ 6	0.03	+ 8	0.04	-23	0.13	55
	8	+22	0.03	+36	0.04	- 7	0.13	55
4	7	+12	0.08	-17	0.16			
	8	+45	0.08	-42	0.16			55
6A	1	+ 8	0.02	- 8	0.09			
	2	+14	0.02	- 9	0.09			
	3	0		0		0		
	4			+12	0.04	- 6	0.07	13
	5			+20	0.04	-11	0.07	13
	6	0		0		0		
	7	+ 7	0.15	+ 5	0.20	-19	0.33	
	8	+11	0.15	+32	0.20	-10	0.33	30
6B	1	+15	0.03	+10	0.11			
	2	+17	0.03	+ 9	0.11			
	3	0		0		0		
	4	- 4	0.02	+10	0.05			
	5	- 7	0.02	+17	0.05			
	6	0		0		0		
	7	+ 9	0.10	+ 4	0.15			
	8	+19	0.10	+30	0.15			32
7A	1	-21	0.02	-19	0.08	0	0.17	
	2	-55	0.02	-57	0.08	-62	0.17	50
	3	-22	0.02	-31	0.08	-37	0.17	
	4	- 8	0.02	-16	0.08	-20	0.13	
	5	-30	0.02	-38	0.08	-35	0.13	
	6	0						
	7			-31	0.14	-41	0.21	
	8			-90	0.14	-82	0.21	14, 35
7B	1	- 8	0.01	+17	0.06			35
	2	-29	0.01	+39	0.06			35
	3	- 8	0.01	+17	0.06			
	4	0		-11	0.08			16
	5	0		-22	0.08			
	6	0		0		0		
8	1	0	0.02	+10	0.06	-11	0.09	
	2	-15	0.02	+22	0.06	-23	0.09	11
	3	- 3	0.02	+10	0.06	-10	0.09	
	4	- 8	0.02	- 9	0.09			11
	5	-20	0.02	-24	0.09			11
	6	0		0		0		
	7	- 5	0.05	+16	0.11			
	8	- 9	0.05	+11	0.11			
9	1	+22	0.04	+30	0.06	+33	0.13	16, 50
	2	+38	0.04	+53	0.06	+58	0.13	15, 50
	3	- 6	0.04	+ 9	0.06	+ 9	0.13	15, 50
	4	+26	0.06	-23	0.11			15, 50
	5	+34	0.06	-34	0.11			15, 13, 50
	7	-24	0.07	-18	0.15	+20	0.25	14, 55, 4.2
	8	-28	0.07	+35	0.10	+30	0.25	14, 55, 4.2

TABLE 2

Maximum Shear and Principal Stresses Computed from Strains Measured by Rosettes on Radial Web A

Salvo	Major Principal Stress pounds per square inch	Minor Principal Stress pounds per square inch	Maximum Shear Stress pounds per square inch	Orientation of Principal Axis degrees clockwise from axis of Gage 1	Estimated Time from Instant of Firing seconds
1	- 120	-1000	440	-42	0.04
	- 190	- 940	375	-43	0.09
	- 580	- 680	50	- 3	0.13
2	+ 445	-1155	800	-38	0.02
	+ 255	-1225	740	-15	0.06
	+1460	+ 900	685	+64	0.17
3	+ 100	- 750	425	-26	0.03
	+ 740	+ 240	250	-23	0.05
	- 55	- 845	395	-33	0.08
7A	- 150	-1700	775	-45	0.02
	- 315	-1815	750	-40	0.08
	+ 300	-1900	1100	-34	0.17
7B	- 820	+ 150	480	-45	0.01
	+1240	+ 220	510	+45	0.06
8	+ 260	- 370	315	-42	0.02
	+ 150	+ 700	275	+45	0.06
	- 170	- 740	285	-46	0.09
9	+1110	- 420	765	+34	0.04
	+1650	+ 10	820	+36	0.06
	+1810	0	905	+36	0.13

error existed in the records because of the inability of the amplifiers to respond properly to signals of low frequency. The magnitude of error was determined from the shape of the response of the amplifiers to a step pulse such as that employed in calibration; the method of making corrections is described in the Appendix. Corrections were made only to the records having the greatest amplitude of signal. The error in peak strains was less than 4 per cent in every case except for Gage 2, Salvo 9; the error in that record amounted to 17 per cent.

The stresses in the webs of the base ring are produced during firing of the turret guns by either the horizontal force H and the vertical force V_1 from the roller tracks, or the force V_2 from the holding-down clip as indicated in Figure 1. These loads result from the overturning moments of the director due to the effect of gun blast, and from the inertia of the director to motion induced by vibrations of the ship that accompany the shock of firing. Salvo 9 was fired with the guns trained away from the director so that the blast effect may have been negligible. Salvos 6A, 6B, and 8 were fired from the after turret, nearly half the ship's length from the director, and therefore may have introduced only a small blast effect. Salvos 1, 2, 3, 4, 7A, and 7B were fired from the forward turrets, about a quarter of the ship's length from the director, and therefore probably introduced a somewhat greater blast effect than Salvos 6A, 6B, and 8. The stresses in the webs might therefore be expected to have a pattern that would be related to the external forces accompanying each salvo. That is, for example, the overturning moment of the director due to blast from a certain salvo from nearby guns should produce stresses greater than those that accompany a salvo from more remote guns. Likewise, the time between the instant of firing and the occurrence of a peak strain might be expected to correspond to the interval of time required for the blast-pressure wave to travel from the muzzle of the guns to the director. In no salvo, however, was such a systematic relation found to exist between the positions of the guns with respect to the director and the magnitude and shape of the stress-time relationship. The inertia and blast effects thus appear to be combined in a random and indeterminate way. It is believed that among factors interfering with a direct relationship are the reflections of blast-pressure waves from surrounding structure, the chance position of the director on its roller track, and the ripple of fire of guns in the same turret.

The frequencies of the cyclic variations of strain that were discerned in the records correspond to the natural frequencies of portions of the ship structure connected to the gun director. The lowest observed frequency of 4.2 cycles per second agreed well with the transverse cantilever frequency of the main-battery-director tower, and coincidentally with the multi-noded lateral flexural frequency of the hull.* Both of these vibrations were excited mainly by Salvo 9 during which broadside firing induced a considerable lateral vibration of the ship and superstructure, and produced alternations of strain in the web because of the inertia effect of the director. The observed frequency of 11 cycles per second agreed with the fore-and-aft and transverse frequencies of the secondary-battery-director tower. The other observed frequencies of 15, 30, and 55 cycles per second probably correspond to the natural frequencies of local elements of the gun-director structure such as the base ring and its supporting structure.

The principal stresses and the maximum shear stresses in the radial webs could be calculated only where complete data from rosettes were available. Multiplying by E the strain observed from a single gage gives a stress that would have existed if the axis of the gage had been in alignment with a uniaxial stress. In cases where the stress condition is more complicated, the

---

* The natural frequencies of various portions of the ship structure were determined by independent (4) steady-state vibration tests.

calculation has no validity, and is only of qualitative value for comparing measurements at various stations.

CONCLUSIONS

The stresses measured in the webs of the gun-director base ring are very low. Although it is not known if higher stresses existed elsewhere in the ring, the measurements indicate that the webs could be reduced in size without seriously impairing the strength of the ring. Complete elimination of the radial webs, however, might lead to dangerous stress conditions on the inner corners of the ring section, and the safety of this modification cannot be assured without tests of rings so altered.

REFERENCES

(1) Conference at David Taylor Model Basin on 21 February 1944 attended by Lt. Comdr. R.F. Wilson, USNR, and Lt. J.V. Keith, USNR, of the Naval Gun Factory, and Comdr. J.S. Parkinson, USNR, H.R. Thomas, and Ensign E. Wenk, Jr., USNR, of the Taylor Model Basin.

(2) BuOrd CONFIDENTIAL letter NP 7/s71 of 28 April 1944 to TMB.

(3) "Graphical Solution of 45-Degree Strain Rosette Data," by M.E. Duke and E. Wenk, Jr., TMB Report in preparation.

(4) TMB CONFIDENTIAL letter C-S87-19/A11-(1) of 17 August 1944 to BuShips, Physics (332).

(5) "Mathematical Methods in Engineering," by Th. von Kármán and M.A. Biot, McGraw-Hill Book Company, New York, 1940, page 408.

APPENDIX 1

THE DERIVATION OF CORRECTIONS TO THE RECORDED STRAINS

Strains in the radial webs of the base ring of the Mark-37 gun director were measured by metalectric strain gages arranged in a 45-degree rosette pattern. Each gage was connected in a direct-current Wheatstone bridge circuit so that any variation in strain produced a change in resistance of the gage and an unbalance of the bridge. This unbalance in the form of a change in voltage was amplified by vacuum tubes and was recorded on sensitized paper with a string oscillograph.

It was known that the amplifiers employed in the test had characteristics of poor response to driving pulses of low frequency, so that the magnitude of the recorded input might be in error. A system for correcting the recorded signal has been derived by Lieut. Comdr. D. Bancroft, USNR, and a summary of the method is outlined in the following.

The dynamical characteristics of many physical systems, regardless of the type of excitation, can be defined in terms of an operator, the operational impedance $Z(p)$.* This means that if the output is $R(t)$, then the input $S(t)$ is calculated by

$$Z(p)R(t) = S(t) \qquad [1]$$

For any given system, the operator can be determined by actually measuring the response $A(t)$ to a unit step and calculating $Z(p)$ by

$$Z(p) = \frac{1}{p\int_0^\infty A(t)\,e^{-pt}\,dt} \qquad [2]$$

where t is the interval of time from the beginning of the pulse. Proof of these propositions is given in "Mathematical Methods in Engineering" (5).

Consider the case in which the response to a unit function can be represented analytically by a conventional decrement expression**

$$A(t) = e^{-\alpha t}(1 - \beta t) \qquad [3]$$

---

* The operator p denotes differentiation, whereas $1/p$ denotes integration.

** This is approximately the response of a 2-stage capacity-coupled amplifier to a suddenly applied voltage that decays exponentially.

where α and β are constants. With this response, the operational impedance $Z(p)$ found from Equation [2] is

$$Z(p) = \frac{1}{\frac{p}{p+\alpha} - \frac{\beta p}{(p+\alpha)^2}} \qquad [4]$$

That is,

$$Z(p) = 1 + \frac{\alpha+\beta}{p} + \frac{\beta^2}{p^2} + \cdots \qquad [5]$$

where it is to be remembered that $1/p$, $1/p^2$, $\cdots$ $1/p^n$ represent the first, second, $\cdots$ nth integrals of $R(t)$.

Thus, the input $S(t)$ of the system subjected to any arbitrary pulse can be written in terms of the measured response $R(t)$ as

$$S(t) = Z(p)R(t) = R(t) + (\alpha+\beta)\int_0^t R(t)dt + \beta^2\int_0^t\int_0^t R(t)dt\,dt + \cdots \qquad [6]$$

The corrections which must be added to the measured response in order to obtain the actual input are the terms

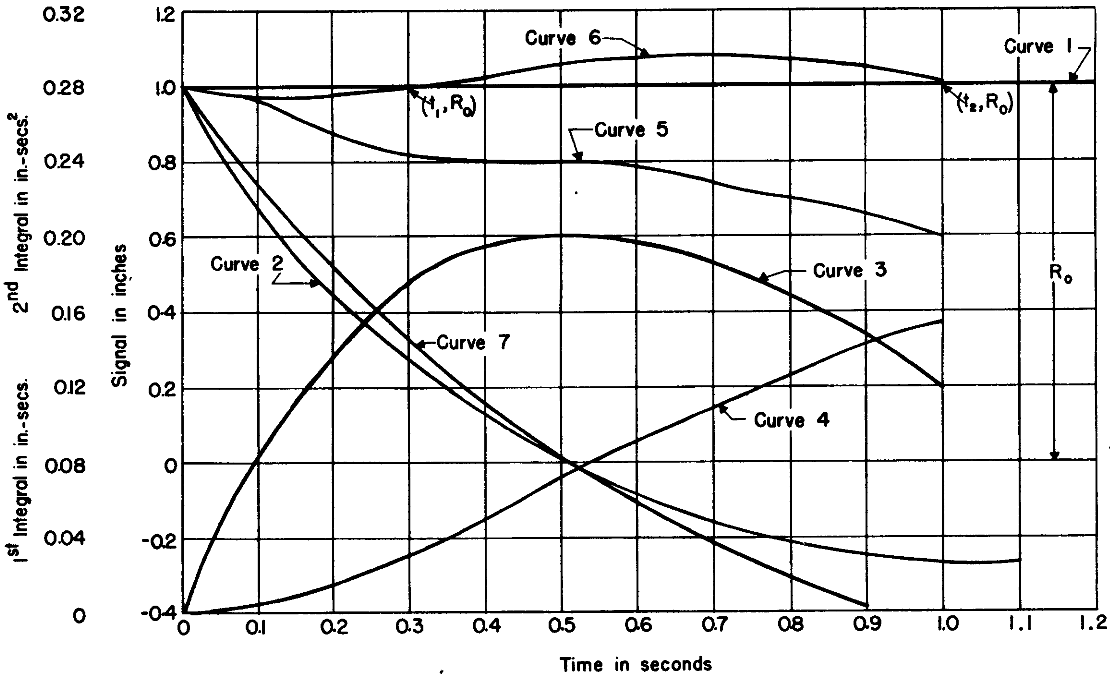
$$\text{Correction} = (\alpha+\beta)\int_0^t R(t)dt + \beta^2\int_0^t\int_0^t R(t)dt\,dt + \cdots \qquad [7]$$

This procedure can now be applied to a specific set of strain records made during the test described in this report. A step pulse was employed for calibration of the equipment prior to the test. A typical response curve is shown as Curve 2 in Figure 3. The pulse was created by switching a fixed resistor in parallel with the gage so as to change the effective resistance of the gage by an amount corresponding to a known strain. Whereas the exact response to such a step pulse should be a straight horizontal line, Curve 1, the measured response, Curve 2, indicates that considerable decay of the signal occurs with time during amplification.

The equation of the response curve was assumed first to be $A_1(t) = e^{-\alpha t}(1 - \beta t)$.* The constants required to make this curve fit the measured response curve were determined as follows: the constant β was determined from the intercept at $y = 0$; α was then found from the slope of the best straight line passed through the points of the plot of log $e^{-\alpha t}$ against t. The values determined in this manner were $\alpha = 0.72$ and $\beta = 1.92$. Employing these values of the constants, the assumed equation was plotted as Curve 7,

---

* This equation of decay does not adequately describe the response of all amplifiers to a step pulse, but was employed as the analytical basis for the derivation of an empirical solution to the problem.



Curve 1 = Exact Step Pulse Response

Curve 2 = Measured Calibration Response $A(t)$ for Channel 8

Curve 3 = $\int_0^t A(t)\,dt$

Curve 4 = $\int_0^t\int_0^t A(t)\,dt\,dt$

Curve 5 = Corrected Response Curve $S(t) = A(t) + (\alpha + \beta)\int_0^t A(t)\,dt + \beta^2\int_0^t\int_0^t A(t)\,dt\,dt$
where $\alpha = 0.72$ and $\beta = 1.92$

Curve 6 = Corrected Response Curve $S(t)_c = A(t) + k_1\int_0^t A(t)\,dt + k_2\int_0^t\int_0^t A(t)\,dt\,dt$
where $k_1 = 3.15$ and $k_2 = 5.88$

Curve 7 = $A_1(t) = e^{-\alpha t}(1 - \beta t)$ where $\alpha = 0.72$ and $\beta = 1.92$

Figure 3 - Step Pulse Calibration and Response Curves

The measured values given are for Channel 8 of the equipment employed to measure strains in the base ring of the Mark-37 Gun Director.

in Figure 3. The first and second integrals of the original response curve were derived graphically and employed in the correction consisting of the first two terms of Equation [7]. Since additional terms were comparatively small, their use in the correction was not warranted. The response curve as corrected is shown as Curve 5 in Figure 3.

The output from a step pulse is a straight horizontal line, Curve 1, and it can be seen that the corrected response curve, Curve 5, deviates appreciably from the true response curve except for only small values of time. This indicates that the assumed equation of decay $A_1(t)$, Curve 7, does not accurately fit the measured response, Curve 2. Obviously, the measured response can be better corrected by the inverse process of forcing several of the points of Curve 5 to fall on the true response curve. A procedure employing this method of correction was adopted so that a correction curve usable at greater intervals of time could be obtained.

The general form of Equation [7] for the corrected response curve was employed, but was expressed as

$$S(t)_c = A(t) + K_1\int_0^t A(t)\,dt + K_2\int_0^t\int_0^t A(t)\,dt\,dt \qquad [8]$$

where K_1 and K_2 are constants, and $S(t)_c$ is the corrected response which approaches the original input $S(t)$. The constants K_1 and K_2 were derived empirically as follows: The corrected response curve was passed through two selected points (t_1, R_0) and (t_2, R_0) whose ordinates were equal to the height of the exact response, $R(0)$. Thus, at these particular points, the corrected response curve must bear the relationship

$$S(t_1)_c = S(t_2)_c = R(0) \qquad [9]$$

In this case, the response curve was corrected arbitrarily at the points $t_1 = 0.3$ second and $t_2 = 1.0$ second. Using Equations [8] and [9], two simultaneous equations for $S(t_1)_c$ and $S(t_2)_c$ were thus derived, each containing K_1 and K_2. The values of $A(t)$, and the first and second integrals of $A(t)$ were read directly from the plotted curves at the abscissas t_1 and t_2; after solving the equations, $K_1 = 3.15$ and $K_2 = 5.88$.*

The expression for the corrected response curve was subsequently derived by substituting the values of the constants K_1 and K_2 in Equation [8]. The result is plotted as Curve 6 in Figure 3; its deviation from the step pulse is less than 8 per cent for even large intervals of time.

As was pointed out in the foregoing, the operational impedance $Z(p)$ found from a unit step may be applied to any transient in that particular system. The strains recorded during the firing trials may thus be corrected by the constants derived from the calibration response. A sample correction is indicated in Figure 4. The strain record for Gage 8, Salvo 4, was plotted and the first and second integrals were determined graphically. By using the

---

* These values are to be compared with corresponding values of $(\alpha + \beta) = 2.64$ and $\beta^2 = 3.70$ of Equation [7]. These corrected constants can be used to determine an empirical expression

$$A(t) = -1.31\,e^{-1.58t}\sin(1.84t - 0.86)$$

which agrees more closely with the response curve, Curve 2, than does Curve 7.

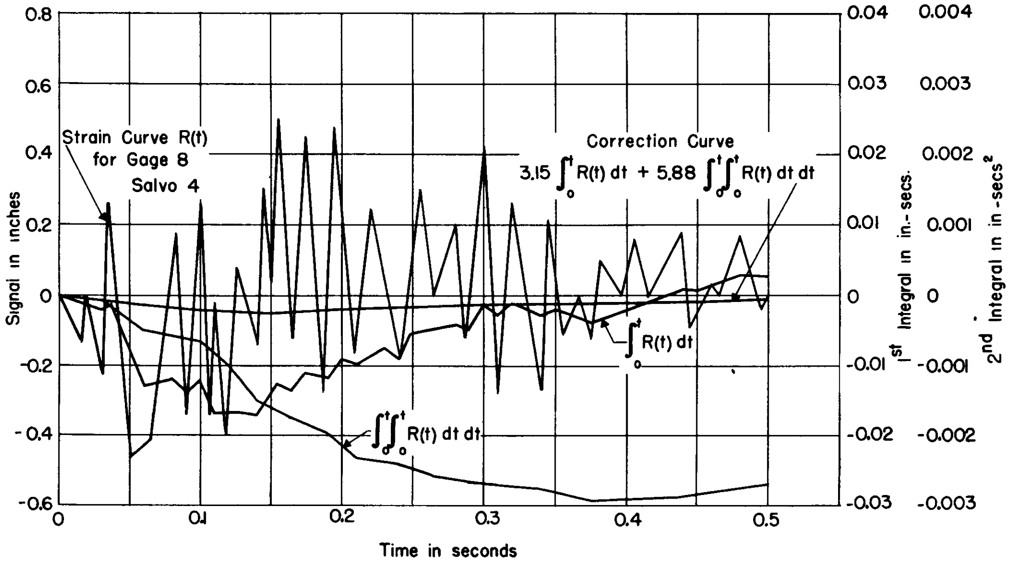


Figure 4 - Strain Record and Correction for Gage 8, Salvo 4

The correction at any time t must be added algebraically to the original strain curve to produce the true strain.

previously computed values of the constants K_1 and K_2, the correction to the signal can be calculated for every value of t from

$$\text{Correction} = K_1 \int_0^t R(t)\,dt + K_2 \int_0^t\int_0^t R(t)\,dt\,dt \qquad [10]$$

The correction is indicated in Figure 4 and is added algebraically to the measured response to give the true signal.

For this particular strain record the error of the peak strain is negligible but in the cases where the period* of the transient is of longer duration, the decay of the response is great enough to introduce a large error. If the response to a unit step is measured, however, the correction may be determined regardless of the shape of the driving pulse.

---

* Here, the period of the transient refers to the interval of time required for the recorded signal to go from zero to peak value and back to zero again.