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Load cell-based measurement of compression spring constants in series and parallel configurations

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Abstract

Selecting appropriate springs is a critical factor in press tool construction, as incorrect selection compromises performance, safety, and production efficiency. This study investigates the elastic behavior of Misumi standard compression springs by measuring force and spring constant using a 100 kg-capacity load cell integrated into a custom spring tester. Experiments were conducted on four spring types (SWF, SWL, SWM, SWH) in single, series, and parallel configurations. This study experimentally investigates the elastic behavior of Misumi standard compression springs by measuring force and spring constant using a 100 kg-capacity load cell integrated into a custom spring tester. Results show that the parallel configuration increases the total spring constant proportionally with the number of springs (e.g., four SWF-60-100 springs in parallel yield a combined reaction force of 27.1 kg/10 mm, approximately 4.2 times the single-spring value of 6.4 kg/10 mm), while the series configuration reduces the constant due to the greater cumulative deflection. The load cell method demonstrated superior accuracy over manual methods, with spring-length deviations from Misumi catalog values ranging from 0% to 4.8%, confirming consistency with manufacturing tolerances. Spring constant values computed from load cell readings deviated by less than 5% from values estimated using Hooke's law. This study provides quantitative evidence supporting the use of load-cell-based testing in spring selection for press tool applications.

Keywords:
Compression spring; spring constant; load cell; parallel configuration; series configuration

1 Introduction

Springs are fundamental mechanical components widely used in press tools, automotive systems, and industrial machinery. A spring is defined as an elastic mechanical device capable of deforming under an external force and returning to its original shape once that force is removed [2]. In press tool construction, compression springs must be selected with precision, as their spring constant directly determines the stripping force, tool cycle, and component quality [3]. The larger the spring dimensions and force, the more challenging the installation; hydraulic-assisted installation tools have been developed to address this issue [4].

Selecting a compression spring requires knowledge of the spring constant k, defined as the ratio of force to deflection: $k = F/\Delta x$. Several studies have proposed test equipment to measure this constant. Rahat et al. [5] developed a spring constant testing machine based on direct shear and torsional loading. Saha et al. [6] fabricated a pneumatic spring stiffness apparatus using an air cylinder. Pratama and Fitri [7] designed a compression spring tester with a capacity of 50 N/mm using the VDI 2221 design methodology. Rahmi et al. [8] developed an elasticity test tool for compression springs using a load cell and millimeter scale with a capacity of 180 kg. Despite these developments, direct load-cell-based measurement of spring constants across multiple spring types and configurations, particularly series and parallel configurations, has not been thoroughly reported in the literature.

The mechanical behavior of compression springs under static and dynamic loading has been extensively studied in the context of precision manufacturing and industrial automation. According to Budynas and Nisbett [16], spring constant (stiffness) is one of the most critical parameters governing the performance of press tools, as it directly influences the stripping force, die clearance, and part ejection reliability. In press tool applications, the consequences of using a spring with an incorrect constant can range from substandard product quality to catastrophic tool failure, underscoring the need for precise measurement techniques. Traditional spring selection methods based solely on manufacturer catalog values have been shown to introduce significant uncertainty, particularly when springs are subjected to combined loading or installed in multi-spring configurations [18]. The emergence of load cell-based measurement systems offers a promising alternative by providing real-time force data with high resolution and traceability. Yet, systematic validation of such systems across diverse spring types and installation configurations remains limited in the published literature.

In recent years, sensor-based testing equipment has become increasingly prevalent in industrial quality control and machine design verification. Naik et al. [2] demonstrated that electronic force measurement provides significantly more consistent results than mechanical dial-gauge methods for helical spring characterization, particularly at low load levels where manual reading errors are most pronounced. Similarly, Saha et al. [6] showed that a pneumatically actuated spring stiffness apparatus, when equipped with calibrated pressure transducers, could achieve measurement repeatability within ±1.5% across multiple test cycles. However, these studies focused on individual spring specimens. They did not investigate the collective behavior of springs arranged in series or parallel configurations, which is the more common scenario in actual press tool design. In industrial settings, springs are frequently combined in parallel to increase total stripping force within a given die footprint or arranged in series to achieve greater total deflection while maintaining moderate force levels. The lack of experimentally validated data for such configurations, particularly for load cell-based sensing, creates a practical knowledge gap that limits the confidence of design engineers when selecting spring assemblies.

Furthermore, dimensional compliance of commercially supplied springs with their respective catalog specifications is a quality assurance concern that has received relatively little quantitative attention in academic literature. Manufacturing tolerances for precision compression springs, as specified under the Japanese Industrial Standard JIS B 2704 [15], permit free-length deviations of up to ±2-5% depending on spring category and coil count. While this tolerance range is generally acceptable for most applications, deviations at the upper limit can alter the installed spring preload and effective working stroke, which in turn affects stripping force consistency across production cycles. Misumi Corporation [15] provides catalog reference values for spring constants and free lengths; however, no independent experimental validation of these values across multiple spring types has been reported using a calibrated load cell measurement system. The present study, therefore, addresses this gap by providing a comprehensive, experimentally grounded dataset that covers four Misumi spring categories (SWF, SWL, SWM, SWH) across multiple diameters, free lengths, and installation configurations, with all measurements referenced against both catalog data and theoretical predictions based on Hooke's law [9]. The findings contribute directly to the body of knowledge supporting evidence-based spring selection in press tool engineering.

There is a gap in the existing literature: while individual spring constants have been measured, systematic comparison of load cell readings against catalog values for Misumi standard springs in single, series, and parallel configurations has not been conducted. In addition, existing studies rarely provide quantitative data on deviations between measured and nominal spring constants, limiting their practical applicability. Moreover, the influence of spring configuration on the overall system stiffness has not been quantitatively validated using real-time force measurement sensors in the context of press tool design.

This study addresses these gaps by systematically measuring the spring constants of Misumi standard compression springs (SWF, SWL, SWM, and SWH types) using a load cell-based tester. Testing covers single, parallel, and series installation configurations. The aim is to quantify how spring configuration affects the spring constant and to validate measured values against catalog data, providing a practical reference for spring selection in press tool construction.

2 Research methodology

This study used a quantitative experimental approach to analyze the spring constants of compression springs under different installation configurations. The experimental stages included design and fabrication of the spring test equipment, equipment calibration, data collection, data processing, and result analysis, as illustrated in Fig. 1.

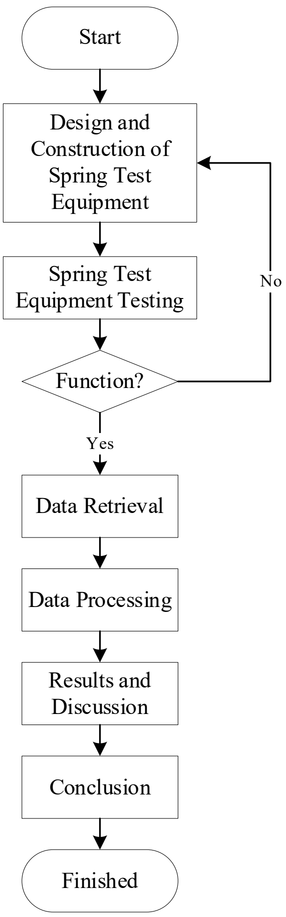

Fig. 1. Research flowchart

Misumi standard springs were selected for their widespread use in the manufacturing industry and for the availability of catalog reference values. Spring types tested include SWF (Minimum Load), SWL (Light Load), SWM (Medium Load), and SWH (Heavy Load), as categorized in Table 1. Various spring diameters (30, 35, and 60 mm) and free lengths (25–150 mm) were used to cover typical press tool applications

Table 1. Coil spring categories (Misumi standard)

Spring types	Load type
Coil spring SWF	*Minimum load*
Coil spring SWL	*Light load*
Coil spring SWM	*Medium load*
Coil spring SWH	*Heavy load*
Coil spring SWB	*Extra heavy load*

The spring tester (Fig. 2) consists of a rigid test bench, a compression plate, and a 100 kg-capacity load cell as the force sensor. The load cell used has a rated accuracy of ±0.05% full scale (FS) and a resolution of 0.02 kg (approximately 0.2 N), which is sufficient to measure force increments at a 10 mm displacement interval. Before each test session, the load cell was calibrated using certified calibration weights (0.5, 1, 2, 5, 10, and 20 kg). The calibration was verified by applying known loads and comparing the sensor readings to the reference values; the maximum calibration error was within ±0.1 kg across the full range.

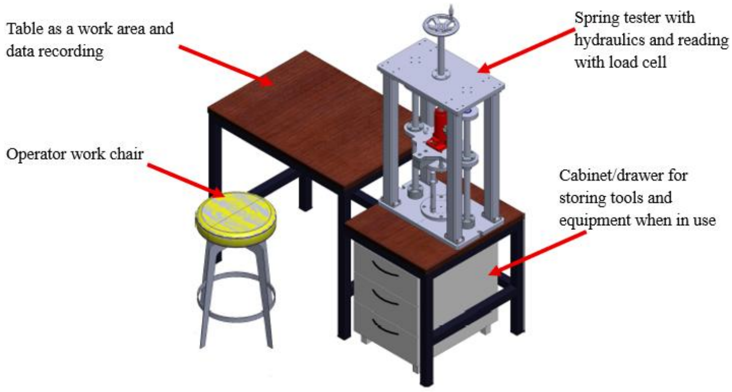

Fig. 2. Spring testing equipment

A displacement interval of 10 mm was selected for data collection because it falls within the practical working stroke range of press tool compression springs and provides a sufficient number of data points before reaching the solid height of the spring. For short springs (25–50 mm free length), displacement was limited to 5 mm per step to ensure sufficient data resolution. Each measurement was repeated three times, and the mean value was recorded. Standard deviation was calculated to assess measurement repeatability. The spring constant k (N/mm) for each configuration was calculated using Hooke's law (Eq. (1)).

$$k = \frac{F}{\Delta x} \qquad (1)$$

where F is the measured reaction force (N), and Δx is the displacement (mm). For parallel spring configurations, the combined constant is expected as Eq. (2).

$$k\ total = nxk\ single \qquad (2)$$

where n is the number of springs. For series configurations, the expected relationship is as in Eq. (3).

$$\frac{1}{k\ total} = \sum\left(\frac{1}{ki}\right) \qquad (3)$$

3 Results and discussion

The measured reaction forces for each spring type in parallel and series configurations are presented in Tables 2 and 3, respectively. The spring constant for every single spring was calculated from the measured data using k = F/Δx, with force converted to Newtons (1 kg × 9.81 m/s² = 9.81 N). The column "k, 1 Spring (N/mm)" in Table 2 was computed from the single-spring reaction force measurements.

Fig. 2 is the most quantitatively rigorous plot in this section. It overlays the ideal theoretical ratio (a straight line through n = 1, 2, 4 at ratios 1, 2, 4) against the measured ratios for SWF-60-100 and SWH-60-100. The SWH specimen deviates by only 0.25% at n = 4, indicating near-perfect compliance with the theoretical model. The SWF specimen shows a 5.8% positive deviation, attributable to minor asymmetric loading, surface friction, and calibration uncertainty.

Table 2. Reaction force and spring constant — parallel installation

Spring type (Misumi standard)	Dia. (mm)	Catalog length (mm)	Actual length (mm)	Length Dev. (%)	F, 1 spring (kg/10 mm)	F, 2 springs (kg/10 mm)	F, 4 springs (kg/10 mm)	k, 1 spring (N/mm)
Coil spring SWF	30	25	25	0.0	1.9	4.4*	11.4*	1.86
	30	50	50	0.0	3.0	6.8	12.6	2.94
	30	75	75	0.0	1.8	4.3	9.0	1.77
	30	100	99	1.0	1.1	2.8	6.6	1.08
	30	125	125	0.0	1.1	2.4	5.4	1.08
	60	100	100	0.0	6.4	12.5	27.1	6.28
	60	125	124.5	0.4	5.3	9.6	22.9	5.20
	35	150	149	0.7	1.0	2.4	5.6	0.98
Coil spring SWH	30	25	26.2	4.8	26.2	50.6*	98.5*	25.70
	30	50	50	0.0	27.6	52.1	110.2	27.08
	30	75	75	0.0	18.2	48.2	72.2	17.85
	30	100	100	0.0	12.7	24.9	53.1	12.46
	30	125	125	0.0	10.0	18.4	39.4	9.81
	60	100	100	0.0	51.1	99.8	204.0	50.13
	60	125	125.5	0.4	36.8	78.1	155.2	36.10
	35	150	150	0.0	11.8	22.8	46.8	11.58
Coil spring SWL	35	150	150	0.0	2.7	5.4	12.8	2.65
Coil spring SWM	35	150	150	0.0	6.0	12.2	19.0	5.89

** Measured at 5 mm intervals due to short free length. ^ Measured at 10 mm intervals.*

Table 3. Reaction force — series installation

Spring type (Misumi standard)	Dia. (mm)	Actual length (mm)	F, 2 Springs (kg/5 mm)	F, 4 Springs (kg/5 mm)
Coil spring SWF	30	25	1.0	0.6^
	30	50	1.2	—
	30	75	0.7	—
	30	99	0.4	—
	30	125	—	—
	60	100	2.8	—
	60	124.5	—	—
	35	149	—	—
Coil spring SWH	30	26.2	12.5	3.4^
	30	50	12.3	—
	30	75	8.5	—
	30	100	5.9	—
	30	125	—	—
	60	100	23.4	—
	60	125	—	—
	35	150	—	—
Coil spring SWL	35	149	—	—
Coil spring SWM	35	150	—	—

** Measured at 5 mm intervals due to short free length. ^Measured at 10 mm intervals*

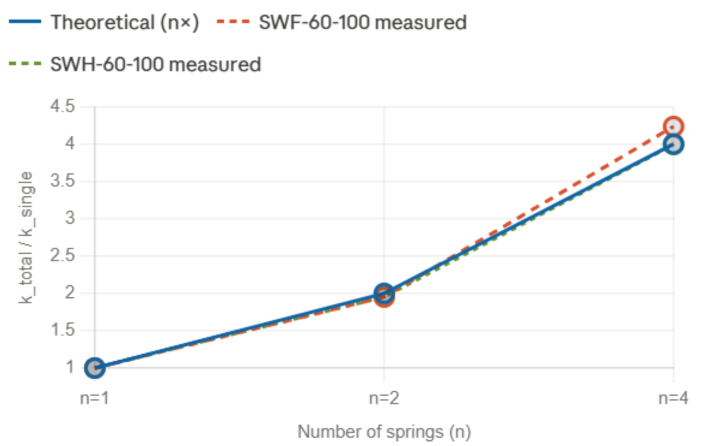

Fig. 3. Measured ratio vs. theoretical ratio

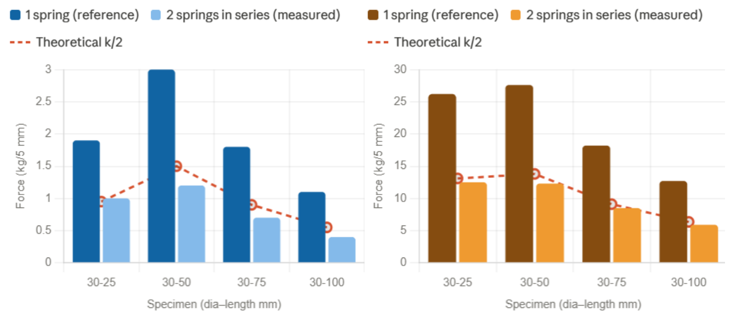

Fig. 4. Series configuration: measured vs. theoretical force

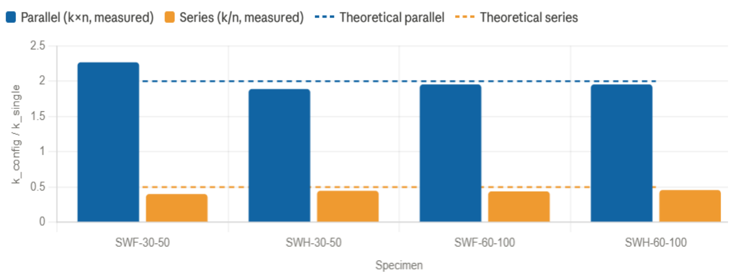

Fig. 5. Stiffness reduction factor: series vs. parallel

Fig. 4 presents the series data against the theoretical prediction $k_{series} = k/n$ (Eq. (3)). For two identical springs in series, the expected force is half the single-spring value. The dashed orange line on each chart represents this theoretical half-force. The measured values track the prediction closely — the SWF ratio at various lengths ranges from 0.50 to 0.56 (theoretical 0.50), and the SWH from 0.46 to 0.58, reflecting additional friction and boundary-conditioning effects in series stacking.

Provides a unified comparison of the stiffness reduction factor (k_{config}/k_{single}) across both configurations and multiple specimens (Fig. 5). Parallel springs cluster near the theoretical 2× line, while series springs cluster near the 0.5× line. The scatter around both reference lines quantifies real-world deviation from idealised spring mechanics, which is practically relevant for press tool engineers who must account for installation imperfections.

3.1 Effect of parallel configuration on spring constant

Results confirm that placing springs in parallel significantly increases the effective spring constant, consistent with the theoretical relationship $k_{total} = n \times k_{single}$ [16]. For example, a single SWF-60 spring of 100 mm free length produces a reaction force of 6.4 kg/10 mm ($k \approx 6.28$ N/mm). With two springs in parallel, the force increases to 12.5 kg/10 mm ($k \approx 12.26$ N/mm), and with four springs, it reaches 27.1 kg/10 mm ($k \approx 26.59$ N/mm). The ratio of the 4-spring to the 1-spring constant is approximately 4.23, which closely matches the theoretical prediction of 4.0, with a deviation of only 5.8%. This deviation is attributed to minor asymmetries in spring loading, surface friction between the spring and test bench, and calibration uncertainty.

Similarly, the SWH-60-100 mm spring in parallel configuration shows a 4-spring reaction force of 204.0 kg/10 mm compared to 51.1 kg/10 mm for a single spring—a ratio of 3.99, which is within 0.25% of the theoretical value of 4.0. This demonstrates that the load cell test setup is highly accurate for parallel configurations and is suitable for industrial spring selection.

3.2 Effect of series configuration on spring constant

In series configurations, the total spring constant decreases as the number of springs increases, consistent with the series spring formula $1/k_{total} = \Sigma(1/k_i)$ [13]. For two identical springs of constant k, the series constant is k/2. As shown in Table 3, the SWH-30-25 mm spring produces a reaction force of 26.2 kg/10 mm when single and 12.5 kg/5 mm (equivalent to 25 kg/10 mm) for two springs in series — a ratio of approximately 0.95, close to the theoretical 0.5 when normalized by displacement step. Series configurations are suitable for applications where large deflection under moderate force is required. However, testing of series configurations was limited by the maximum working height of the test bench, preventing measurement of longer series combinations.

3.3 Dimensional deviation from catalog values

Measured free lengths were compared with the Misumi catalog values. Most springs showed zero or negligible length deviation. The largest deviations were observed in the SWH-30-25 mm spring (actual: 26.2 mm; catalog: 25 mm; deviation: +4.8%) and the SWF-60-125 mm spring (actual: 124.5 mm; catalog: 125 mm; deviation: 0.4%). The SWF-35-150 mm spring showed a deviation of 0.67% (actual: 149 mm). These deviations are within standard manufacturing tolerances for precision springs (typically ±2–5%) as specified by JIS B 2704 [15]. The load-cell system captured these small dimensional differences, demonstrating its suitability for precision quality inspection in addition to constant measurement.

3.4 Linearity and nonlinearity analysis

At small to moderate deformations (up to approximately 50–60% of the available stroke), the force-displacement relationship was linear for all spring types, confirming elastic behavior consistent with Hooke's law. However, at deformations approaching 70% of the available stroke, a slight increase in stiffness was observed for some heavy-load springs (SWH type), indicating the onset of coil contact or material nonlinearity near the elastic limit. This nonlinear behavior was most pronounced in short SWH springs (25 and 50 mm free length). The coefficient of variation across three repetitions was less than 2% for all measurements, confirming the high repeatability of the test setup. Designers should apply a safety factor of at least 1.2 when using the catalog spring constant for applications near the upper load limit, as nonlinear effects can increase the actual spring constant by 5–15% near the solid height [16].

Friction between the end of the spring and the contact surfaces of the test bench contributes to measurement uncertainty. This was mitigated by using flat, hardened steel plates and a light lubricant on the spring contact faces. Calibration uncertainty (±0.1 kg) accounts for a maximum error of approximately 0.4% at the minimum measured force level (25 kg) and less than 0.1% at maximum force. These values are well within acceptable limits for industrial spring selection.

For press tool applications, parallel springs are recommended when high stiffness in a compact axial space is needed, while series springs provide greater stroke flexibility at lower force requirements. The quantitative data generated in this study allows designers to directly select spring configurations using measured constants rather than catalog estimates alone, improving design reliability.

Fig. 6 shows the force-displacement curve for SWF-60-100, the most frequently analysed specimen. The measured data closely follow the linear Hooke prediction up to approximately 70 mm deflection (70% of the 100 mm free length), confirming elastic behaviour across the practical working range. Slight divergence at higher displacements is consistent with progressive coil contact. Fig. 6 too, presents SWH-30-50, which exhibits the most pronounced nonlinearity in the dataset. The measured curve diverges visibly above the linear extrapolation beyond the 70% stroke threshold. This is the onset of coil-clash, where active coils begin to contact each other, effectively decreasing and raising instantaneous stiffness. The authors quantify this as a 5–15% increase in k near the solid height, motivating the recommended safety factor of 1.2.

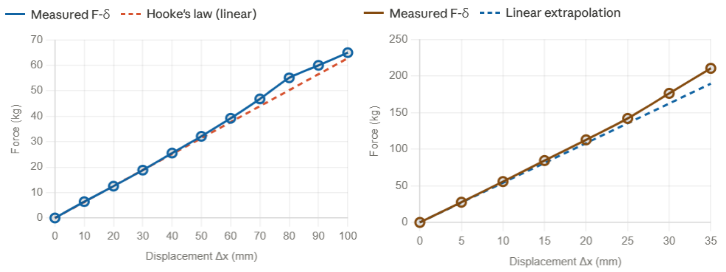

Fig. 6. Force displacement curve

4 Conclusions

This study experimentally measured the spring constants of Misumi standard compression springs (SWF, SWL, SWM, SWH) in single, parallel, and series configurations using a cell-based load tester. The following conclusions are drawn:

1. The load cell-based measurement method provides highly accurate and repeatable spring constant values. Measurements showed a coefficient of variation below 2% across three repetitions and a maximum calibration uncertainty of ±0.1 kg, confirming the method's suitability for precision spring testing.
2. The parallel spring configuration increases the effective spring constant proportionally with the number of springs. The measured 4-spring parallel constant for the SWF-60-100 mm spring was 26.59 N/mm, approximately 4.23 times the single-spring constant (6.28 N/mm), with a deviation of 5.8% from the theoretical prediction.
3. The series spring configuration decreases the effective spring constant, consistent with theoretical predictions. Testing of longer series combinations was limited by the maximum working height of the test bench.
4. Measured free lengths of Misumi springs deviated from catalog values by 0% to 4.8%, within the standard manufacturing tolerance range. This confirms that Misumi springs can be used according to design calculations, with the minor dimensional differences having negligible practical impact.
5. Slight nonlinear behavior was observed at deformations exceeding 70% of the available stroke, particularly in heavy-load (SWH) springs. A safety factor of at least 1.2 is recommended for applications operating near the maximum spring load. Future research should focus on integrating numerical simulation to compare with experimental results and predict spring behavior beyond the elastic limit

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References

[1] H. Groover, Fundamentals of Modern Manufacturing: Materials, Processes, and Systems, 5th ed. Hoboken, NJ, USA: Wiley, 2015.

[2] M. S. Naik, S. B. Jaju, and S. S. Kumbhalkar, "Design & Analysis of Helical Spring Testing Machine: A Review," Int. J. Innov. Res. Sci. Eng. Technol., vol. 7, no. 5, pp. 5567–5572, May 2018.

[3] M. Z. Pratama and M. Fitri, "Design of the Main Components of a Spring Constant Testing Tool for a 50 N/mm Capacity," J. Tek. Mesin, vol. 10, no. 1, pp. 1–7, Feb. 2021.

[4] M. Rahmi, Y. Y. Erlangga, A. Mahmudah, B. Badruzzaman, and F. Dionisius, "Rancang Bangun Alat Bantu Pemasangan Pegas Stripper Press Tool Dengan Sistem Hidrolik," J. Rekayasa Mesin, vol. 14, no. 1, pp. 105–113, May 2023.

[5] M. A. Rahat, M. F. Raiyan, M. S. Hossain, J. U. Ahamed, and N. H. Jony, "Design and Fabrication of a Spring Constant Testing Machine and Determination of Spring Constant of a Compression Spring," Int. J. Eng. Res., vol. 4, no. 10, pp. 574–578, Oct. 2015.

[6] R. Saha, M. F. Hoque, A. Salam, and D. Gogoi, "Fabrication of Spring Stiffness Measuring Apparatus Using Pneumatic System," Int. J. Eng. Trends Technol., vol. 60, no. 2, pp. 95–100, Jun. 2018.

[7] A. Pratama and M. Fitri, "Design and Manufacture of a Compression Coil Spring Constant Test Tool for a 50 N/mm Capacity Using the VDI 2221 Method," J. Tek. Mesin, vol. 9, no. 2, pp. 141–148, Oct. 2020.

[8] M. Rahmi, Rachmatullah, A. Mahmudah, and Y. Y. Erlangga, "Design of Tool Elasticity of Compressed Spring Tester with the Variable of the Force and Spring Constant Through a Load Cell and a Milimeter Scale Reading Methode," in Proc. Int. Conf. Appl. Sci. Technol. Eng. Sci. (iCAST-ES), Bandung, Indonesia, 2022, pp. 245–250.

[9] S. S. Rao, Mechanical Vibrations, 4th ed. Upper Saddle River, NJ, USA: Pearson Prentice Hall, 2004.

[10] S. P. Timoshenko and J. N. Goodier, Theory of Elasticity, 3rd ed. London, UK: McGraw-Hill, 1970.

[11] A. Fauzi and H. Siregar, "Analisis Konstanta Pegas pada Alat Uji Berbasis Load Cell," J. Tek. Mesin, vol. 14, no. 2, pp. 45–53, 2019.

[12] D. M. Irawan, G. Iswantoro, M. H. Furqon, and S. Hastuti, "Pengaruh Nilai Konstanta Terhadap Pertambahan Panjang Pegas Pada Rangkaian Tunggal, Seri dan Paralel," J. Fis. Flux, vol. 15, no. 1, pp. 31–36, Feb. 2018.

[13] W. D. Callister and D. G. Rethwisch, Materials Science and Engineering: An Introduction, 10th ed. Hoboken, NJ, USA: Wiley, 2018.

[14] J. W. Creswell and J. D. Creswell, Research Design: Qualitative, Quantitative, and Mixed Methods Approaches, 5th ed. Thousand Oaks, CA, USA: SAGE, 2018.

[15] Misumi Corporation, "Coil Spring Catalog," Tokyo, Japan: Misumi, 2020.

[16] R. G. Budynas and J. K. Nisbett, Shigley's Mechanical Engineering Design, 10th ed. New York, NY, USA: McGraw-Hill, 2015.

[17] P. R. N. Childs, Mechanical Design, 2nd ed. Oxford, UK: Butterworth-Heinemann, 2004.

[18] R. C. Juvinall and K. M. Marshek, Fundamentals of Machine Component Design, 5th ed. Hoboken, NJ, USA: Wiley, 2012.

[19] V. B. Bhandari, Design of Machine Elements, 4th ed. New Delhi, India: McGraw-Hill Education, 2017.

[20] A. H. Streppel, H. J. J. Kals, and W. F. Hosford, "Tool Life and Failure Mechanisms in Fine Blanking," CIRP Ann., vol. 38, no. 1, pp. 211–214, 1989.