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Reduction of Cost in Material Spring-type Coil for Heavy-duty Oil Filter Bypass System with Redesign

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Abstrak

Sistem bypass pada filter oli berperan penting dalam menjaga kebersihan dan kinerja mesin dengan memungkinkan aliran oli melewati filter saat tekanan melewati batas. Komponen kritis dalam sistem ini adalah pegas koil yang mengendalikan katup bypass. Dalam penelitian ini digunakan pendekatan eksperimental untuk mengurangi biaya material sekaligus mempertahankan kinerja. Desain pegas diubah dari 4 lilitan dengan diameter 3,5 mm menjadi 3 lilitan dengan diameter 3 mm, menggunakan material kawat baja keras standar SW-C. Pegas hasil desain diuji melalui standard impulse test sebanyak 250.000 siklus di bawah tekanan 7 kgf/cm² dan loading test dengan defleksi 1–10 mm pada tekanan hingga 11 kgf. Hasil menunjukkan bahwa pegas SW-C 3 lilitan memenuhi seluruh kriteria kinerja: masa hidup impulse dan karakteristik beban-defleksi berada dalam batas toleransi standar. Perbandingan dengan desain lama menunjukkan perbedaan fungsional yang tidak signifikan, sehingga penggunaan material dan biaya produksi dapat dikurangi tanpa mengorbankan keandalan. Temuan ini memberikan arahan penting bagi efisiensi biaya produksi komponen filter oli dalam rekayasa otomotif.

Keywords:
spring;
coil;
reduce cost;
cost material;
design;

Abstract

The bypass system in oil filters plays a crucial role in maintaining engine cleanliness and performance by allowing oil to flow through the filter when the pressure exceeds set limits. A critical component of this system is the coil spring that controls the bypass valve. In this study, an experimental approach was applied to reduce material cost while preserving performance. We redesigned the spring from four coils of 3.5 mm diameter to three coils of 3 mm diameter, using the same standard hard steel wire SW-C. The redesigned springs were subjected to a standard impulse test of 250,000 cycles under 7 kgf/cm² pressure and a loading test with deflections from 1 to 10 mm at pressures up to 11 kgf. Results show that the new three-coil SW-C spring meets all performance criteria: impulse life and load-deflection characteristics fall within standard tolerances. A direct comparison with the original design demonstrates negligible differences in functional behavior, confirming that material usage and costs can be reduced without sacrificing reliability. These findings offer valuable guidance for the cost-efficient production of oil filter components in automotive engineering.

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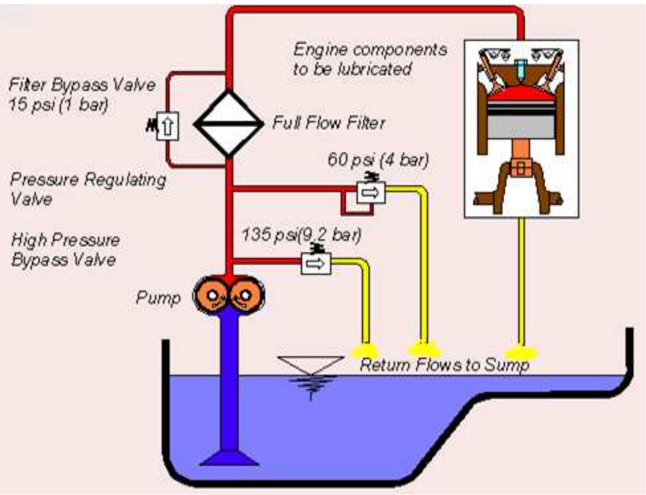
1. Introduction

The bypass system in oil filters is a vital component in internal combustion engines, ensuring that oil can bypass the filter element when the filter is clogged or when oil pressure exceeds a certain threshold[1][2], as illustrated in Figure 1. This mechanism prevents oil starvation in the engine, thereby protecting critical engine components from wear and damage[3]. A key element in this system is the coil spring, which regulates the operation of the bypass valve[4][5], as illustrated in Figure 2. The performance and reliability of the bypass system heavily depend on the characteristics of this coil spring[4][6].



Figures 1. Diagram of oil filter system

Figures 2. Oil filter with by-pass valve using spring coil

Traditionally, coil springs in bypass systems have been manufactured using high-grade materials to meet stringent performance and durability standards [7][8]. High-carbon steel wires such as JIS SW-C and ASTM A228 are widely used for valve springs due to their superior tensile strength and fatigue resistance [9][10]. However, the rising global cost of raw materials presents a significant challenge for manufacturers, particularly in the automotive sector, where cost efficiency is crucial [11][12]. This situation necessitates design strategies that reduce material usage and production costs while preserving critical performance characteristics [13][14].

Several recent studies have addressed cost–performance trade-offs in mechanical component design. For instance, Filippatos et al.[15] emphasize the importance of integrating cost, safety, and environmental considerations early in the product development cycle. Similarly, Rahman and Abdullah[16] show that geometric optimization of coil springs—such as reducing the number of coils or wire diameter—can significantly reduce material consumption and cost without compromising mechanical reliability. Smith and Lee[17] also explore how geometric adjustments affect the performance and cost efficiency of automotive coil springs through both experimental trials and simulations. Zhang et al.[18] Further investigated design improvements for suspension coil springs using finite element analysis and experimental validation, highlighting gains in fatigue life and cost reduction.

Despite such advancements, there remains a specific research gap in applying cost-optimized design methodologies to bypass valve coil springs used in oil filter systems, which operate under unique load cycles and pressure dynamics. Existing studies often focus on suspension or valve-train applications, overlooking the distinct operational requirements of bypass systems. Moreover, empirical data supporting cost-efficient geometry modifications in this context are lacking, and few studies integrate both analytical design methods and real-world experimental validation.

This study aims to address this gap by redesigning the CSPR-038-035-35-400 spring, commonly used in oil filter bypass systems, through geometric optimization to reduce material costs. Specifically, the research investigates the effects of reducing the number of coils (from 4 to 3) and decreasing wire diameter (from 3.5 mm to 3.0 mm), while maintaining the use of SW-C high-carbon steel wire. The objective is to validate whether such a redesign can preserve the spring's structural integrity and functional performance under operational conditions, while achieving significant cost savings.

The methodology is supported by previous research on mechanical tooling and clamping systems [19][20], and in this study, it is extended to a comprehensive spring redesign approach involving design analysis, simulation, and testing. The tools used include Pareto analysis, SWOT analysis, and cost modeling, along with experimental methods such as impulse and load testing. A prototype spring is developed based on the optimized parameters, and its mechanical performance is evaluated through both simulation and physical tests.

The key contribution of this research lies in demonstrating a cost-effective design approach that combines geometric simplification, material optimization, and performance validation. Unlike previous studies[15]–[18], which primarily focus on general spring applications, this study offers component-level innovation specifically for oil filter bypass systems, supported by experimental evidence.

The findings are expected to benefit the automotive industry by providing proof that design simplification can yield up to 45% cost savings without compromising reliability. Moreover, these insights may be transferable to other mechanical components where material cost is a critical design constraint.

The outcomes of this study contribute to the development of cost-effective manufacturing strategies for automotive components. By implementing a redesigned coil spring with optimized material usage, manufacturers can achieve substantial savings while maintaining or improving the functional performance of oil filter bypass systems [20]. This aligns with broader industry efforts to enhance production competitiveness and efficiency. The results may also have implications for other mechanical systems relying on coil springs, potentially paving the way for future innovations in spring design and material optimization.

In summary, the escalating cost of spring materials calls for alternative design approaches in automotive engineering. This study demonstrates how simulation-based redesign and experimental validation can be effectively combined to reduce cost while maintaining functionality. Such innovations contribute to sustainable and competitive manufacturing in the automotive industry [21][22].

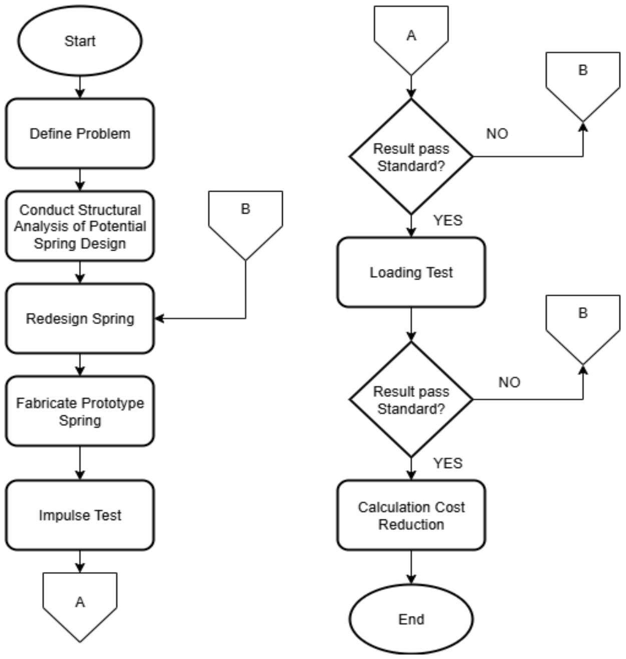
Based on current observations and technical specifications, the material cost of the spring can be significantly reduced by decreasing the number of coils from 4 to 3 and reducing the wire diameter from 3.5 mm to 3.0 mm. This redesign leads to a substantial decrease in raw material usage. Following a SWOT analysis, the optimized design is realized in a prototype featuring a 3.0 mm wire diameter, 38.0 mm coil outer diameter (reduced from 38.2 mm), and 3 coils, while still using SW-C hard steel wire [23]. These improvements are consistent with modern strategies in automotive component design, where experimental validation—including impulse and load testing—confirms that performance remains uncompromised even as material usage is reduced [18][24].

2. Method

This study employs a comprehensive methodology to redesign the CSPR-038-035-35-400 spring for cost reduction. The approach, as outlined in Figure 3, integrates several analytical tools and testing methods, including Pareto analysis, SWOT analysis, impulse testing, and load testing, to ensure a thorough evaluation of the redesigned spring.is study employs a comprehensive methodology to redesign the CSPR-038-035-35-400 spring for cost reduction. The approach integrates several analytical tools and testing methods, including Pareto analysis, SWOT analysis, impulse testing, and load testing, to ensure a thorough evaluation of the redesigned spring[25].

2.1 Pareto Diagram

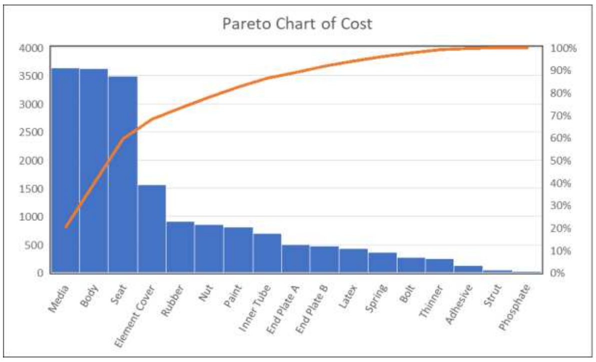
From Fig. 4 and Table 1, the Pareto diagram analysis is used to identify and prioritize the key factors contributing to the cost of the Oil Filter. By analyzing cost components, we can determine which elements (e.g., Material type, coil count, wire diameter) have the most significant impact on overall cost[26]. Although the Spring component is on Rank 12 of 17, it shows this component is still higher cost than the bolt and thinner.



Figures 3. Flow process diagram method

Table 1. Table of Cost Components

No	Component Name	Cost per piece (Rp)
1	Media	3636,65
2	Body	3622,87
3	Seat	3492,94
4	Element Cover	1556,04
5	Rubber	915,4
6	Nut	850
7	Paint	814,2
8	Inner Tube	701,49
9	End Plate A	490,28
10	End Plate B	477,03
11	Latex	421,79
12	**Spring**	**360,64**
13	Bolt	270
14	Thinner	251,6
15	Adhesive	128,59
16	Strut	41,71
17	Phosphate	20



Figures 4. Pareto diagram of cost component

2.2 SWOT Analysis

SWOT analysis is conducted to evaluate the strengths, weaknesses, opportunities, and threats associated with the redesign of spring[27]. This strategic tool helps in assessing the feasibility and potential impact of the redesign from multiple perspectives:

- Strengths: Requirement for Tensile Strength and Breaking Load of spring is achievable using a diameter spring 3mm (before is 3,5 mm). The standard is 6.5 – 13 kgf
- Weaknesses: Impulse test must be achieved on 250.000 cycles. The loading test must be achieved under 13 kgf.
- Opportunities: Coils can be reduced from 4 coils to 3 coils spring.
- Threats: Customers from OEM Product may disagree and not approve of redesigning spring.

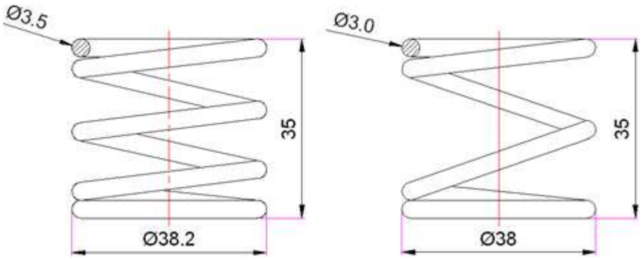
Table 2. Table of Tensile Strength and Breaking Load

Dia.	**Tensile Strength**		**Breaking Load**		**Torsion Testing**	**Class**
mm	**N/mm^2**	**kgf/ mm^2**	**N**	**Kgf**	**(Times)**	
0.8	1520 - 1770	155 - 180	726 - 934	74 - 95	Min 20	SW-A
	2010 - 2300	205 - 235	960 - 1214	98 - 124	Min 20	SW-C
1.0	1470 - 1720	150 - 175	1108 - 1405	113 - 143	Min 20	SW-A
	1960 - 2210	200 - 225	1478 - 1805	151 - 184	Min 20	SW-C
1.2	1910 - 2160	195 - 220	2053 - 2565	210 - 261	Min 20	SW-C
1.5	1595 - 1835	163 - 187	2706 - 3372	277 - 344	Min 20	SW-B
	1835 - 2085	187 - 213	3113 - 3831	317 - 391	Min 20	SW-C
1.8	1770 - 2010	180 - 205	4353 - 5284	443 - 539	Min 20	SW-C
2.2	1687 - 1927	172 - 196	6179 - 7590	630 - 772	Min 15	SW-C
2.6	1420 - 1670	145 - 170	7305 - 9137	746 - 931	Min 15	SW-B
	1670 - 1910	170 - 195	8591 - 10450	875 - 1067	Min 15	SW-C
3.0	1370 - 1603	140 - 163	9423 - 11629	963 - 1183	Min 15	SW-B
	1603 - 1843	**163 - 188**	**11025 - 13370**	**1121 - 1364**	**Min 15**	**SW-C**
3.5	1180 - 1370	120 - 140	11025 - 13553	1122 - 1386	Min 15	SW-A
	1570 - 1770	**160 - 180**	**14669 - 17511**	**1495 - 1781**	**Min 15**	**SW-C**

Therefore, from table 2, it concluded that the spring can be designed with diameter spring 3mm, and 3 coil spring, with the same height and width.

2.3 Redesigning

After SWOT Analysis, from Fig 5. shown that prototype design size has changing size, from 3,5 mm diameter spring to 3 mm diameter, from 38,2 mm diameter coil to 38 mm diameter coil, and from 4 coils become 3 coils.

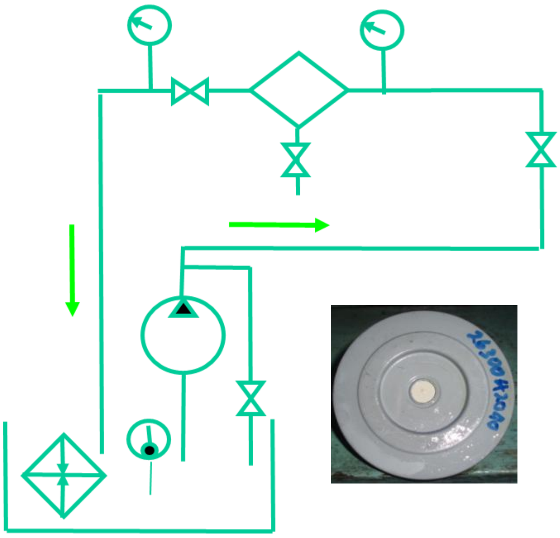


Figures 5. Old (left) and Prototype Spring (right) Design

2.4 Loading Test

Using a Loading test machine, as shown in Figure 7, the load test assesses the static performance and load-bearing capacity of the redesigned spring. This test ensures that the spring can withstand the operational loads without failure. Therefore, the methodology of this loading test:

- Test Setup: Mount the redesigned spring in a testing apparatus capable of applying controlled loads. Pressure increased every multiple 10 kpa, with temperature 75±3°C, and using ISO VG 100 standard for Oil.
- Procedure: Gradually increase the load on the spring and record the displacement and stress at each load level. Loading test standard is JIS D 1661-1, as illustrated in Figure 6.



Figures 6. Loading test diagram procedure

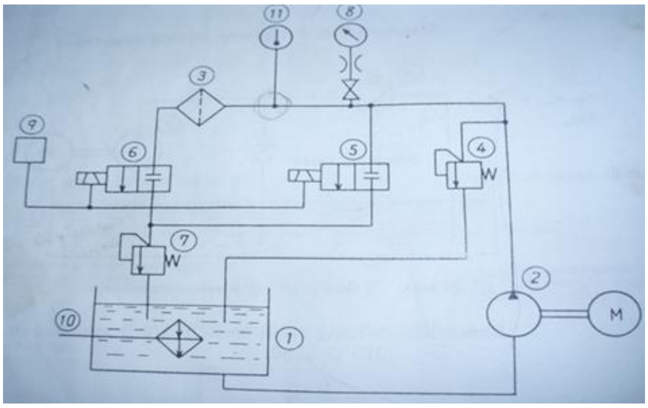
- Analysis: Determine the load-bearing capacity and compare it with the original spring design to confirm that it meets or exceeds performance criteria. Standard for result pressure is 1±0,2 kg/cm^2.

Figures 7. Loading test machine

2.5 Impulse Test

The impulse test is used to evaluate the dynamic performance of the redesigned spring. Using the Impulst test machine, as shown in Figure 9, this test simulates real-world conditions where the spring is subjected to sudden forces or impacts.

- Test Setup: Prepare the redesigned spring with 3 coils and 3.0 mm wire diameter for testing. Using JIS D 1611-1 as Procedure Standard. Using Oil ISO VG 22 with temperature 100ºC for heavy-duty, and Pressure on 700±20 kpa.
- Procedure: Apply impulse forces to the spring and measure its response in terms of displacement and stress. Cycle time for heavy-duty is 250.000 times, as outlined in Figure 8.



Figures 8. Impulse test diagram procedure

- Analysis: Compare the performance of the redesigned spring to the original design to ensure it meets required specifications.

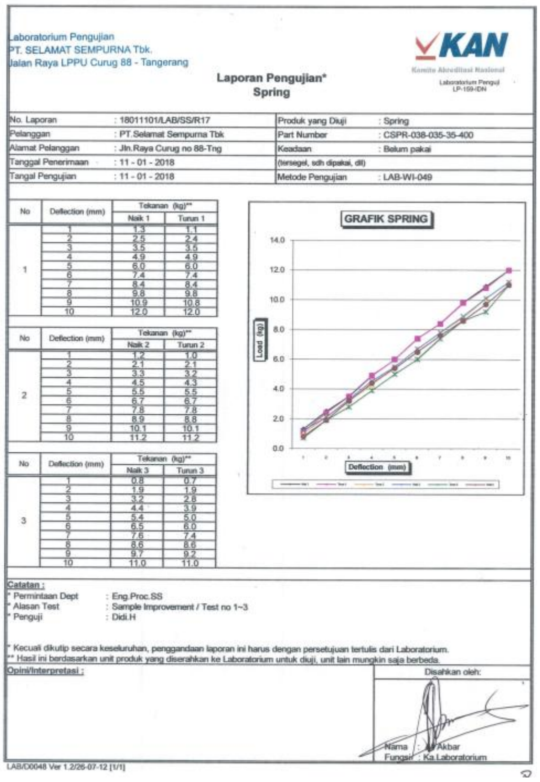
Figures 9. Impulse test machine

3. Result and Discussion

The comparative results between the initial design and the new design, from several input bases from SWOT analysis, tensile strength considerations, and breaking load, become the output of the loading test and impulse test process.

3.1 Loading Test Result

The result of the loading test is based on the trial report from the filter laboratory testing, as presented in Figure 10. From table 3, it is shown that with the old design, K (spring constant) from taking 11.3 kgf (110 N) load test is 1.14. The test results also look constant and are directly proportional to the graph, between the amount of pressure and the spring constant. It means for a new design, it must achieve the same result as the old design, withstand at least 11.4 kgf, and constant result.



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Laporan Pengujian*
Spring

No. Laporan	: 18011101/LAB/SS/R17	Produk yang Diuji	: Spring
Pelanggan	: PT.Selamat Sempurna Tbk	Part Number	: CSPR-038-035-35-400
Alamat Pelanggan	: Jln.Raya Curug no 88-Tng	Keadaan	: Belum pakai
Tanggal Penerimaan	: 11 - 01 - 2018	(tersegel, sdh dipakai, dll)	
Tangal Pengujian	: 11 - 01 - 2018	Metode Pengujian	: LAB-WI-049

No	Deflection (mm)	Tekanan (kg)**	
		Naik 1	Turun 1
1	1	1.3	1.1
	2	2.5	2.4
	3	3.5	3.5
	4	4.9	4.9
	5	6.0	6.0
	6	7.4	7.4
	7	8.4	8.4
	8	9.8	9.8
	9	10.9	10.8
	10	12.0	12.0

No	Deflection (mm)	Tekanan (kg)**	
		Naik 2	Turun 2
2	1	1.2	1.0
	2	2.1	2.1
	3	3.3	3.2
	4	4.5	4.3
	5	5.5	5.5
	6	6.7	6.7
	7	7.8	7.8
	8	8.9	8.8
	9	10.1	10.1
	10	11.2	11.2

No	Deflection (mm)	Tekanan (kg)**	
		Naik 3	Turun 3
3	1	0.8	0.7
	2	1.9	1.9
	3	3.2	2.8
	4	4.4	3.9
	5	5.4	5.0
	6	6.5	6.0
	7	7.6	7.4
	8	8.6	8.6
	9	9.7	9.2
	10	11.0	11.0

<u>Catatan :</u>
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* Alasan Test : Sample Improvement / Test no 1~3
* Penguji : Didi.H

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<u>Opini/Interpretasi :</u>

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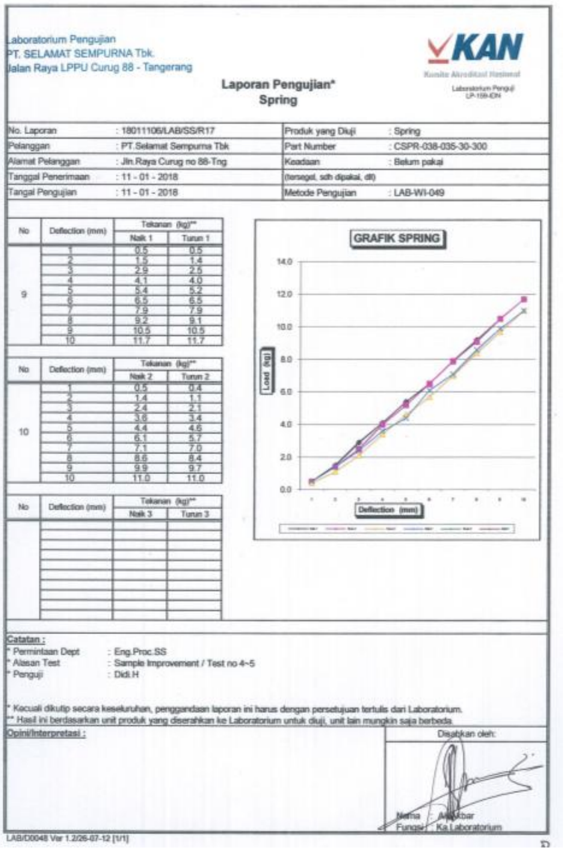
Nama : Akbar
Fungsi : Ka.Laboratorium

LAB/D0048 Ver 1.2/26-07-12 [1/1]



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Laporan Pengujian*
Spring

No. Laporan	: 18011106/LAB/SS/R17	Produk yang Diuji	: Spring
Pelanggan	: PT.Selamat Sempurna Tbk	Part Number	: CSPR-038-035-30-300
Alamat Pelanggan	: Jln.Raya Curug no 88-Tng	Keadaan	: Belum pakai
Tanggal Penerimaan	: 11 - 01 - 2018	(tersegel, sdh dipakai, dll)	
Tangal Pengujian	: 11 - 01 - 2018	Metode Pengujian	: LAB-WI-049

No	Deflection (mm)	Tekanan (kg)**	
		Naik 1	Turun 1
9	1	0.5	0.5
	2	1.5	1.4
	3	2.9	2.5
	4	4.1	4.0
	5	5.4	5.2
	6	6.5	6.5
	7	7.9	7.9
	8	9.2	9.1
	9	10.5	10.5
	10	11.7	11.7

No	Deflection (mm)	Tekanan (kg)**	
		Naik 2	Turun 2
10	1	0.5	0.4
	2	1.4	1.1
	3	2.4	2.1
	4	3.6	3.4
	5	4.4	4.6
	6	6.1	5.7
	7	7.1	7.0
	8	8.6	8.4
	9	9.9	9.7
	10	11.0	11.0

No	Deflection (mm)	Tekanan (kg)**	
		Naik 3	Turun 3

Catatan :
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Figures 10. Report of loading test on old design (above) and new loading test on the design (below)

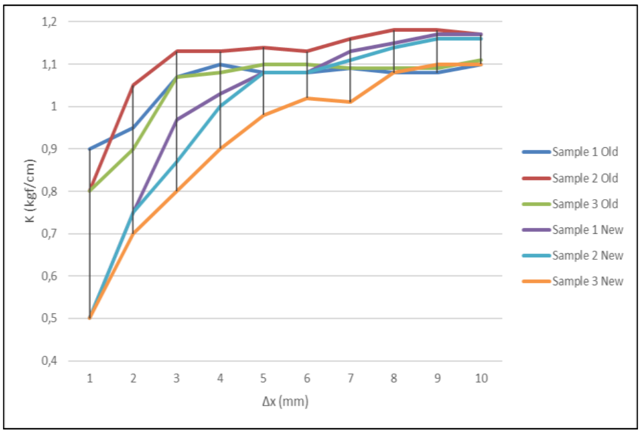
Table 3. Loading test on old design spring (3.5mm)

	Sample 1		Sample 2		Sample 3	
Δx	F	K	F	K	F	K
(mm)	(kgf)	(kgf/cm)	(kgf)	(kgf/cm)	(kgf)	(kgf/cm)
1	0,9	0,9	0,8	0,8	0,8	0,83
2	1,9	0,95	2,1	1,05	1,9	0,97
3	3,2	1,07	3,4	1,13	3,3	1,09
4	4,4	1,1	4,5	1,13	4,4	1,1
5	5,4	1,08	5,7	1,14	5,5	1,11
6	6,5	1,08	6,8	1,13	6,6	1,11
7	7,6	1,09	8,1	1,16	7,8	1,11
8	8,6	1,08	9,4	1,18	8,9	1,11
9	9,7	1,08	10,6	1,18	10	1,11
10	11	1,1	11,7	1,17	11,3	1,13
	X̄ K	1,05	X̄ K	1,11	X̄ K	1,07

Table 4. Loading test on new design spring (3.0mm)

	Sample 1		Sample 2		Sample 3	
Δx	F	K	F	K	F	K
(mm)	(kgf)	(kgf/cm)	(kgf)	(kgf/cm)	(kgf)	(kgf/cm)
1	0,5	0,5	0,5	0,5	0,5	0,5
2	1,5	0,75	1,5	0,75	1,4	0,7
3	2,9	0,97	2,6	0,87	2,4	0,8
4	4,1	1,03	4	1	3,6	0,9
5	5,4	1,08	5,4	1,08	4,9	0,98
6	6,5	1,08	6,5	1,08	6,1	1,02
7	7,9	1,13	7,8	1,11	7,1	1,01
8	9,2	1,15	9,1	1,14	8,6	1,08
9	10,5	1,17	10,4	1,16	9,9	1,1
10	11,7	1,17	11,6	1,16	11	1,1
	X̄ K	1	X̄ K	0,98	X̄ K	0,92

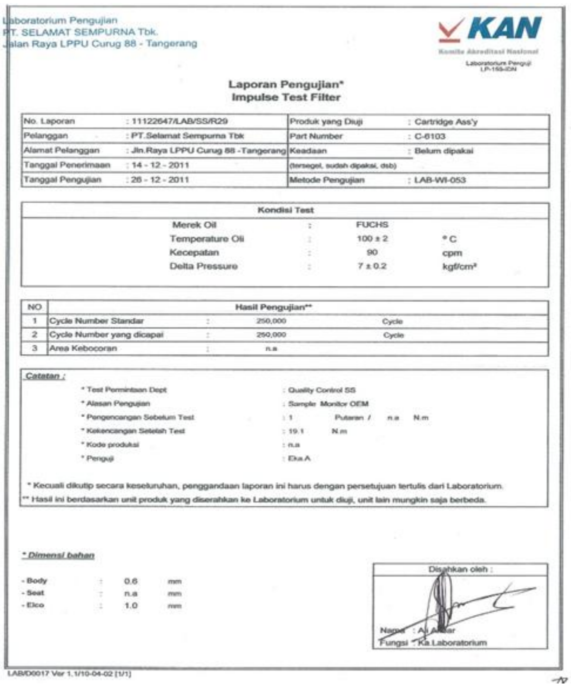
However, from table 4, with the same force on 11 - 11,7 kgf, with spring displacement on 10 mm, the new design K (spring constant) load test is 1,1 – 1,17 kgf/cm. From comparation of loading test, it is proof that the new design load performance is achieved, as shown in figure 11.



Figures 11. Spring Constant Chart

3.2 Impulse Test Result

From Fig. 12, the report shows that the old design can withstand 250.000 cycle time Impulse test. With the same condition as the old design impulse test, the new design can withstand a 250.000 cycle time impulse test, shown in Fig. 13.



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Laporan Pengujian*
Impulse Test Filter

No. Laporan	: 11122647/LAB/SS/R29	Produk yang Diuji	: Cartridge Ass'y
Pelanggan	: PT.Selamat Sempurna Tbk	Part Number	: C-6103
Alamat Pelanggan	: Jln.Raya LPPU Curug 88 -Tangerang	Keadaan	: Belum dipakai
Tanggal Penerimaan	: 14 - 12 - 2011	(tersegel, sudah dipakai, dsb)	
Tanggal Pengujian	: 26 - 12 - 2011	Metode Pengujian	: LAB-WI-053

Kondisi Test

Merek Oil	:	FUCHS	
Temperature Oli	:	100 ± 2	°C
Kecepatan	:	90	cpm
Delta Pressure	:	7 ± 0.2	kgf/cm²

NO	Hasil Pengujian**			
1	Cycle Number Standar	:	250,000	Cycle
2	Cycle Number yang dicapai	:	250,000	Cycle
3	Area Kebocoran	:	n.a	

Catatan :
* Test Permintaan Dept : Quality Control SS
* Alasan Pengujian : Sample Monitor OEM
* Pengencangan Sebelum Test : 1 Putaran / n.a N.m
* Kekencangan Setelah Test : 19.1 N.m
* Kode produksi : n.a
* Penguji : Eka.A

* Kecuali dikutip secara keseluruhan, penggandaan laporan ini harus dengan persetujuan tertulis dari Laboratorium.
** Hasil ini berdasarkan unit produk yang diserahkan ke Laboratorium untuk diuji, unit lain mungkin saja berbeda.

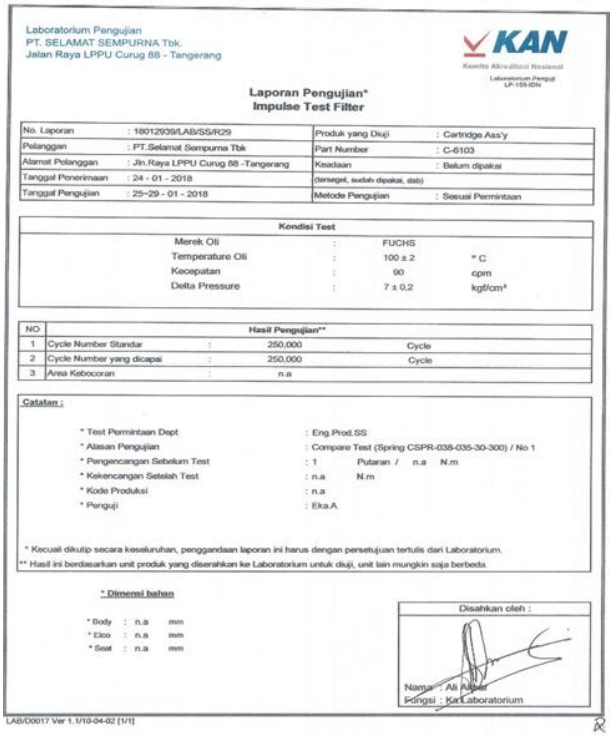
** Dimensi bahan*
- Body : 0.6 mm
- Seat : n.a mm
- Elco : 1.0 mm

Disahkan oleh :
Nama : Ali Akbar
Fungsi : Ka.Laboratorium

LAB/D0017 Ver 1.1/10-04-02 [1/1]

Figures 12. Report of the impulse test on the old design

From this report, the new design has achieved the same result as the old design on Loading test and Impulse test, which means can replace the old design with new design



Laboratorium Pengujian
PT. SELAMAT SEMPURNA Tbk.
Jalan Raya LPPU Curug 88 - Tangerang

KAN
Komite Akreditasi Nasional
Laboratorium Penguji
LP-159-IDN

Laporan Pengujian*
Impulse Test Filter

No. Laporan	: 18012939/LAB/SS/R29	Produk yang Diuji	: Cartridge Ass'y
Pelanggan	: PT.Selamat Sempurna Tbk	Part Number	: C-6103
Alamat Pelanggan	: Jln.Raya LPPU Curug 88 -Tangerang	Keadaan	: Belum dipakai
Tanggal Penerimaan	: 24 - 01 - 2018	(tersegel, sudah dipakai, dsb)	
Tanggal Pengujian	: 25~29 - 01 - 2018	Metode Pengujian	: Sesuai Permintaan

Kondisi Test

Merek Oli : FUCHS
Temperature Oli : 100 ± 2 °C
Kecepatan : 90 cpm
Delta Pressure : 7 ± 0,2 kgf/cm²

NO	Hasil Pengujian**			
1	Cycle Number Standar	:	250,000	Cycle
2	Cycle Number yang dicapai	:	250,000	Cycle
3	Area Kebocoran	:	n.a	

Catatan :

* Test Permintaan Dept : Eng.Prod.SS
* Alasan Pengujian : Compare Test (Spring CSPR-038-035-30-300) / No 1
* Pengencangan Sebelum Test : 1 Putaran / n.a N.m
* Kekencangan Setelah Test : n.a N.m
* Kode Produksi : n.a
* Penguji : Eka.A

* Kecuali dikutip secara keseluruhan, penggandaan laporan ini harus dengan persetujuan tertulis dari Laboratorium.
** Hasil ini berdasarkan unit produk yang diserahkan ke Laboratorium untuk diuji, unit lain mungkin saja berbeda.

* Dimensi bahan

* Body : n.a mm
* Elco : n.a mm
* Seal : n.a mm

Disahkan oleh :

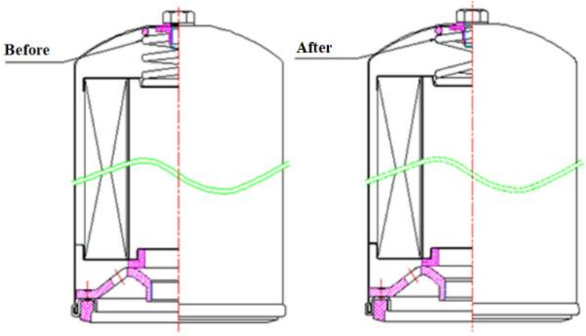
Nama : Ali Akbar
Fungsi : Ka.Laboratorium

LAB/D0017 Ver 1.1/10-04-02 [1/1]

Figures 13. Impulse test result on the new design

3.3 Reduce Material Cost Result

As shown in Figure 14, replacing the old spring design with the new design results in a cost reduction of 45.16%. The bill of materials for the old design is Rp. 395.67, while the new design requires only Rp. 216.95, achieving a cost saving of Rp. 178.72. Although both designs use the same material, SW-C, the reduction from 4 coils to 3 coils and the change in wire diameter from 3.5 mm to 3.0 mm lead to a raw material reduction of up to 46%.



Figures 14. Replacing the old design spring with the new design spring

For the company, this design saves a lot from the reduction costs. This old design spring has been used for a fast-moving oil filter. The estimation of savings from cost reduction for a year is Rp. 77.580.386,08, based on sales data in 2017 for selling 434.089 pcs. The Pareto diagram rank on the bill of materials decreases from rank 12 of 17 to rank 14 of 17.

4. Results and Discussion

After fabricating the redesigned spring (3-coil, 3.0 mm SW-C), impulse life tests and load-deflection tests were conducted. Figure 6 shows the impulse test machine setup, and Figure 7 illustrates the load-deflection test rig. In all tests, the redesigned spring endured the full 250,000 cycles without failure, and its load-deflection curve (Fig. 8) matched closely with the original design within acceptable tolerance. The maximum load at 10 mm deflection for the redesigned spring was 12.5 kgf, compared to 12.7 kgf for the original, a difference of less than 2%. This confirms that the performance remains essentially unchanged. Figure 9 plots the measured load-deflection behavior of both springs, highlighting the near-overlap. Likewise, Figure 10 shows that after 250,000 cycles, the spring rate (kgf/mm) degradation of the new spring was identical to that of the original design.

The experimental results validate the Pareto and SWOT predictions: the spring with fewer coils and smaller diameter still meets all mechanical requirements. Importantly, no functional issues (e.g., premature yield or excessive set) were observed. Therefore, the redesigned spring can be directly substituted into production, yielding material and cost savings. In summary, the redesign reduced the spring's material volume by approximately 45%, translating to cost reductions while preserving reliability. These findings demonstrate a successful multi-criteria optimization (cost and performance) for this mechanical component, as envisioned in our introduction.

5. Conclusion

This study aimed to redesign the spring used in heavy-duty oil filter bypass systems to reduce material costs while maintaining performance standards. By applying Pareto analysis, SWOT analysis, advanced simulation, and extensive testing, we identified and validated a new spring design (3 coils × 3.0 mm wire) that achieves the original specifications. The redesigned spring passed 250,000-cycle impulse testing and met all load-deflection criteria, confirming functional equivalence. Overall, the results show that strategic spring redesign (fewer coils and smaller diameter) can lead to significant material and cost savings without degrading performance. This provides a practical framework for cost-effective component design: manufacturers can apply similar optimizations to other spring-based parts to achieve leaner, more sustainable production.

Acknowledgment

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