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Effect of Architecture and Operating Conditions of Vehicle on Bulb Lifetime in Automotive

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Abstract**—**Automotive lighting is the leading function in the configuration of vehicle architecture. Especially headlights and taillights from external lighting functions are among the structures that determine the stylistic character of the vehicle. At the same time, the fact that lighting functions are related to many other functions brings along difficulties in design. Customers expect maximum quality from the vehicle. In these circumstances, it is necessary to make designs that aim to keep the performance of bulbs with limited working lives at the highest level. With this study, the factors that influence the working lives of filament lamps were examined and bulb explosions that can occur sooner than anticipated in the future were prevented while the vehicle was still in the design phase by determining the relations with electrical, dynamical and static variables. Especially the filaments of the bulbs used in the front lighting of the vehicle are deformed in a shorter time due to the high voltage requirement. In addition to this, rear lighting lamps vibrate as a result of the tailgate opening and closing and cause the filaments to be exposed to high stress. With this study, the findings that cause bulb explosions were evaluated. Among the most important findings: 1. The structure of the cables to the lighting functions of the vehicle and the effect of the voltage values are drawn; 2. The effect of the vibration to bulb throughout the life of the vehicle; 3 The effect of the loads carried to bulb while the vehicle doors are opened and closed. At the end of the study, the maximum performance was established in the bulb lifetimes with the optimum changes made in the vehicle architecture based on the findings obtained.

Keywords**—**Vehicle architecture, automotive lighting functions, filament lamps, bulb lifetime.

I. INTRODUCTION

THE automotive industry develops further day to day and conveys cutting-edge technology to its own architecture. Among the primary purposes of vehicle architecture, which is closely related to the style of the vehicle, are: i) Safety, (ii) Security, (iii) Quality and RAS - Reliability, Availability, Serviceability, (iv) Energy, possibly including performance, (v) Cost, (vi) NVH - noise, vibration, harshness, and (vii) Weight [1]. The structures that compose vehicle architecture are shown in Fig. 1.

Among the most important structures that compose vehicle architecture are external lighting functions. Automotive lighting has been subject to major changes during the last decade. Namely it has acquired more functions in terms of design and safety aspects and is now approaching new technologies like Advanced Front Lighting (AFS) systems or the use of LED applications. However, the rate of filament bulb use on the vehicle is still at around 70% [2] (Fig. 2). In these circumstances, burning out of filament lamps with limited life is an important impact area in terms of quality. For the satisfaction of customers, DFMEAs (Design Failure Mode and Effects Analyses) should be implemented in the most efficient way and the possible mistakes in vehicle production should be prevented in order to avert all negativities.

The filament structures of the filamentary lamps used in automotive consists of "refractory metals". “The refractory metals consist of selected metals with melting points of around 2000 °C and higher. This includes the following metals and their refractory alloys: Tungsten, Molybdenum, Chromium, Tantalum, Niobium and Rhenium” [3]. The first alloy that comes to mind when bulb filaments are mentioned is tungsten. The most important reason for using tungsten for incandescent lamps is that they have a high melting temperature. Tungsten lamps that produce 7.9 lumens per watt came into use in 1903 [4], [5]. Although this alloy resists high temperatures, its structure deteriorates after a while and its use comes to an end. Tungsten is a metal suitable to mechanical deformation because tungsten filaments have high temperature strength. At the same time, some high temperature vacuum devices may use induction heating or direct resistive heating. This process is Coolidge Process and the main features of this process are still valid for today's technology [6], [7], [16]. The most unexpected result was that on working (swaging) sintered tungsten bars down to smaller and smaller sizes, they became increasingly ductile. At low diameters, the wire could even be drawn through diamond drawing dies at moderate temperatures [8].

Today, the ability to use tungsten filaments without fracture is the backbone of the incandescent lamp industry and therefore the automotive lighting industry [9]-[12].

In this study, the structure of the filament lamps used in automotive and the factors that affect their lifespan were explained and the effects of vehicle architecture on bulb life were tested with experiments afterwards. As a result of the experiments conducted, the effects of the most suitable vehicle design on the effective use of bulb life were explained.

II. FILAMENT LAMPS USED IN AUTOMOTIVE

The leading factor that affects vehicle style is external lighting. The filament lamps used in external lighting lamps vary according to lighting functions. This is due to the fact that each lighting function has internationally applicable regulations. All functions must be suitable to the filament lamp category defined in regulations: The definition of filament lamps according to ECE 48, the international general

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regulation for automotive lighting, is as follows: "Filament light source" (filament lamp) means a light source where the element for visible radiation is one or more heated filaments producing thermal radiation [13], [14]. The types of lamps used according to the vehicle exterior lighting functions are shown in Table I and Fig. 3.

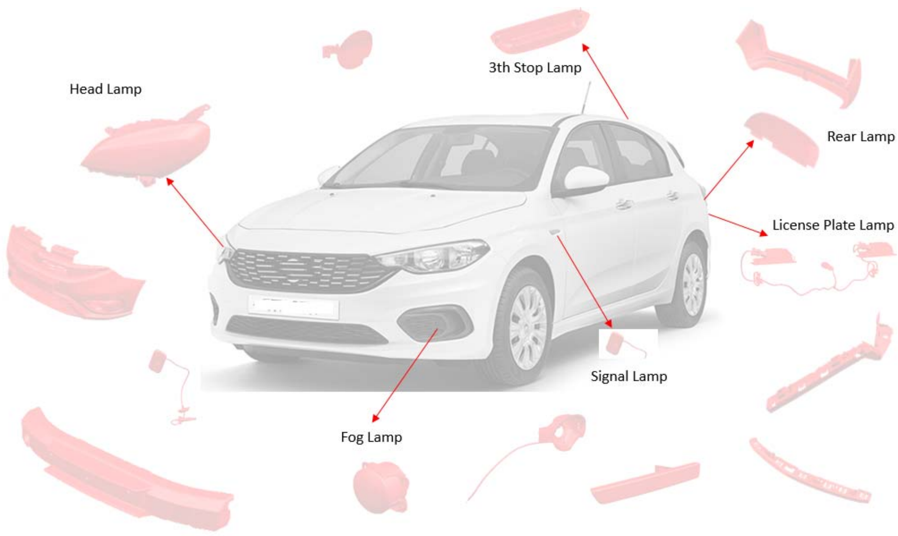

Fig. 1 Vehicle architecture

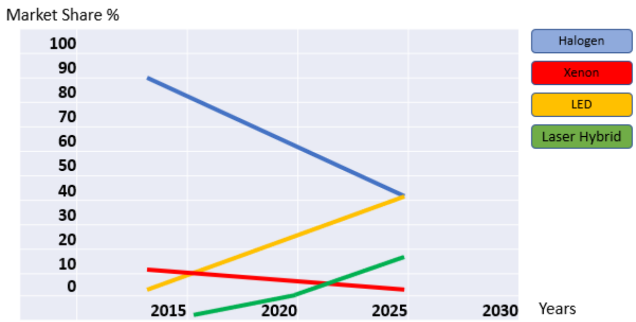

Fig. 2 Usage of bulb on the vehicle

TABLE I
BULBS TYPE

Automotive Lighting Functions	Automotive Bulb Types					
Front Lamps	H1	H3	H4	H7	H11	HB3
Rear Lamps	W16W	P21W	PY21W	WY21W	W5W	
Parking Lamps	T4W	W5W	H6W			
Side Signal Lamps	W5W	WY5W	T4W			
Turn Indicator Lamps	P21W	PY21W	W21W	WY21W		
Fog Lamps	H1	H3	H7			

When starting the vehicle design, the design of the lighting functions in accordance with the vehicle style is also determined. There are light values that each lighting function has to meet. In order to reach these values, the structure of the lighting function is associated with the selected light source and the optical structure to be used.

As it is known, the location of each lighting function in vehicle architecture is different. While the headlights are located in the front of the vehicle, the stop lamps are located near the rear trunk region, called the 5th door of the vehicle. Therefore, each bulb operates in different conditions.

III. Factors Affecting the Lifespan of Filament Lamps

High voltage, outside impact (sudden effects) and foreign substances during bulb production giving rise to inherent stress on filament are determined failures on bulbs. Apart from all these, when we aim to extend bulb life during bulb production, certain chemical and physical rules must be applied. Studies have shown that it is possible to establish long bulb life with the application of the following conditions [17].

The factors for the extension of bulb life with the prevention of filament tungsten deformation are: i) Filament efficiency is increased with creating lower luminous flux on the lower current. ii) Used gas type in the bulb can repress the evaporation of filament tungsten molecule. Bigger molecules are blocked the evaporation of filament. iii) The move of molecule is repressed with increasing the gas pressure.

As the molecular weight of the gases used in the bulb increases, the thermal conductivity of the filament would decrease, the bulb would light brighter, and bulb life would be extended (Fig. 4).

In the technical datasheets where bulb lives are compared, there are TC (by the time the Tc value is reached, 63% of the lamps fail. Min: The Minimum life that is the first failure in the test) and B3 (by the time the B3 value is reached, 3% of the lamps fail) values [15]. When designing vehicle lightning functions, a bulb life comparison between the TC and B3 is also made by looking at technical datasheets in the selection of bulb types. According to bulb manufacturers' result of production conditions, TC and B3 values can be seen changeable. Also, it should not be forgotten that the TC and B3 values are also affected by the gases inside the bulbs.

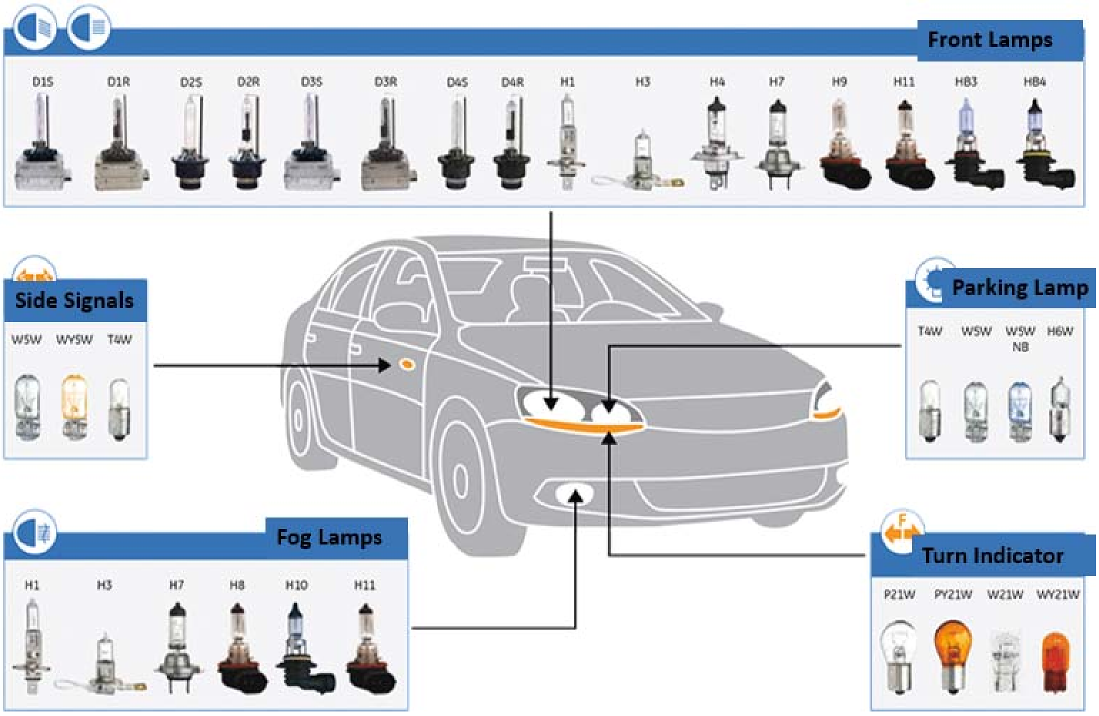

Fig. 3 The types of lamps used according to the vehicle

Bulb Type	Symbol	Atom Size
Vacuum		
Argon	Ar	
Krypton	Kr	
Xenon	Xe	

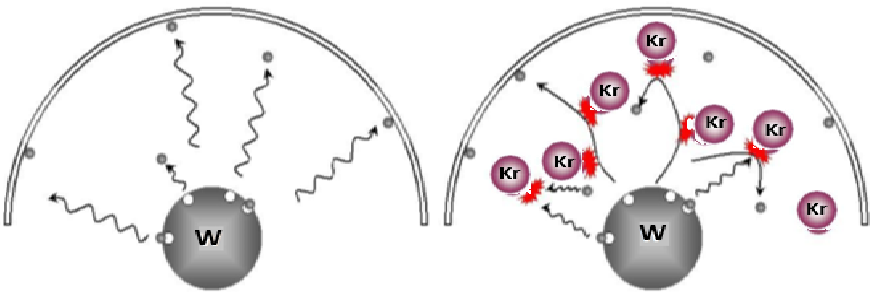

Fig. 4 Molecular weight of the gases in the bulb [15]

IV. Experiments

Voltage Measurement Experiments

The first phase of the study was the measurement of the voltage values to the lighting functions on the vehicle. 3 different vehicles were selected; the H11 bulb lives in the headlamps and later the P21W bulb lives in the stop lamps were compared. The voltage values of the selected vehicles are given in Table II, and the voltage values to the stop lamps are given in Table III.

TABLE II
Voltage Measurement for Headlamp

VOLTAGE MEASUREMENT	Right	Left
Car 1 (H11 Bulb)	13,21 V	13,35 V
Car 2 (H11 Bulb)	13,4 V	14,0 V
Car 3 (H11 Bulb)	12,6 V	12,9 V

TABLE III
VOLTAGE MEASUREMENT FOR STOP LAMP

VOLTAGE MEASUREMENT	Right	Left
Car 1 (P21W Bulb)	13,07 V	13,25 V
Car 2 (P21W Bulb)	13.6 V	13,8 V
Car 3 (P21W Bulb)	13.0 V	13.12 V

Acceleration Measurement Experiments

The second phase of the study was conducted with 2 types of vehicles with different vehicle architectures. First of these was a passenger car and the second was an LCV vehicle. The acceleration values on the P21W bulb in the stop lamp functions located at the rear part of the vehicles were measured with an accelerometer system. The opened baggage doors of the vehicles were closed with normal force and measurements were taken. In the other phase of the experiment, the baggage doors were closed by applying misuse. The measured acceleration values are given as: Passenger Car, normal closing in Table IV and Fig. 5; LCV car, normal closing in Table V and Fig. 6; Passenger Car, Misuse Closing in Table VI and Fig. 7; and LCV Car, Misuse Closing in Table VII and Fig. 8.

TABLE IV
ACCELERATION MEASUREMENT - PASSENGER CAR, NORMAL CLOSING

Time	Left Lamp; Max	Right Lamp; Max	Time	Left Lamp; Max	Right Lamp; Max
s	g	g	s	g	g
0	0,04	0,04	31	0,03	0,04
1	0,03	0,03	32	0,03	0,03
2	0,03	0,04	33	0,03	0,04
3	1,01	1,01	34	0,99	1,06
4	0,20	0,22	35	0,07	0,11
5	0,08	0,08	36	1,01	0,39
6	0,04	0,05	37	0,08	0,08
7	0,04	0,04	38	0,04	0,05
8	0,03	0,04	39	0,04	0,05
9	0,04	0,04	40	0,03	0,04
10	0,08	0,10	41	0,04	0,04
11	0,18	0,15	42	0,13	0,12
12	12,02	12,49	43	0,08	0,08
13	0,55	0,57	44	10,62	10,81
14	0,03	0,03	45	0,76	0,75
15	0,03	0,03	46	0,03	0,04
16	1,84	1,22	47	0,03	0,04
17	0,83	0,84	48	0,03	0,04
18	0,06	0,08	49	0,18	0,22
19	0,14	0,15	50	0,90	0,75
20	0,07	0,07	51	0,25	0,11
21	0,04	0,04	52	0,08	0,06
22	0,04	0,03	53	0,07	0,08
23	0,03	0,04	54	0,04	0,04
24	0,03	0,04	55	0,04	0,04
25	0,03	0,04	56	0,03	0,03
26	0,06	0,05	57	0,03	0,04
27	0,08	0,08	58	0,12	0,10
28	0,07	0,09	59	0,06	0,06
29	12,69	10,83	60	10,34	9,65
30	0,03	0,03			

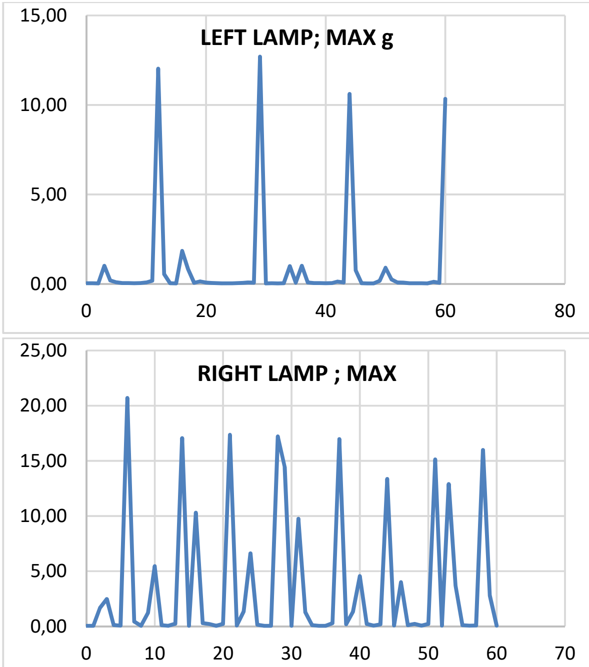

Fig. 5 Acceleration measurement - passenger car, normal closing

TABLE V
ACCELERATION MEASUREMENT - LCV CAR, NORMAL CLOSING

Time	Left Lamp; Max	Right Lamp; Max	Time	Left lamp; max	Right lamp; max
s	g	g	s	g	g
0	0,05	0,04	31	6,55	9,76
1	0,06	0,05	32	0,97	1,29
2	2,07	1,67	33	0,08	0,11
3	1,75	2,48	34	0,06	0,05
4	0,07	0,12	35	0,05	0,04
5	0,06	0,07	36	0,24	0,29
6	23,22	20,71	37	13,19	16,98
7	0,31	0,43	38	0,16	0,19
8	0,05	0,05	39	2,36	1,33
9	1,70	1,21	40	2,28	4,55
10	2,96	5,45	41	0,17	0,21
11	0,09	0,11	42	0,06	0,06
12	0,05	0,05	43	0,26	0,17
13	0,26	0,23	44	9,66	13,36
14	15,84	17,06	45	0,07	0,08
15	0,04	0,05	46	2,11	4,00
16	5,09	10,31	47	0,08	0,11
17	0,14	0,29	48	0,19	0,22
18	0,26	0,20	49	0,06	0,06
19	0,05	0,05	50	0,27	0,22
20	0,26	0,22	51	12,24	15,14
21	15,94	17,36	52	0,05	0,06
22	0,06	0,08	53	9,81	12,90
23	2,23	1,35	54	4,04	3,69
24	5,83	6,61	55	0,09	0,11
25	0,12	0,15	56	0,05	0,06
26	0,06	0,06	57	0,06	0,08
27	0,05	0,05	58	13,22	15,99
28	16,62	17,22	59	2,38	2,81
29	13,95	14,44	60	0,07	0,06

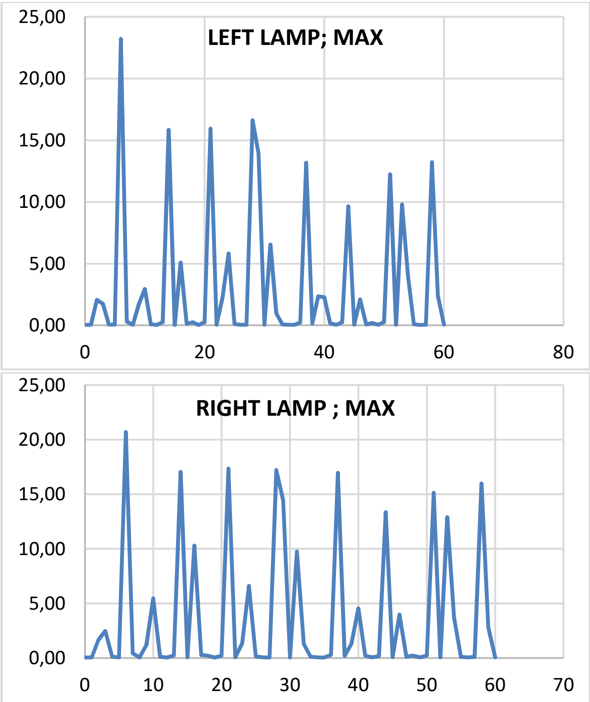

Fig. 6 Acceleration measurement - LCV car, normal closing

TABLE VI
ACCELERATION MEASUREMENT - PASSENGER CAR, MISUSE CLOSING

Time	Left Lamp; Max	Right Lamp; Max	Time	Left Lamp; Max	Right Lamp; Max
s	g	g	s	g	g
0	0,05	0,04	31	7,45	9,61
1	0,07	0,06	32	0,13	0,18
2	2,65	1,31	33	0,19	0,20
3	0,09	0,11	34	0,13	0,21
4	0,10	0,17	35	32,54	23,24
5	0,49	0,44	36	0,08	0,08
6	0,07	0,06	37	2,28	1,60
7	0,20	0,29	38	8,12	8,94
8	24,73	27,22	39	0,28	0,39
9	0,12	0,09	40	0,06	0,06
10	2,23	1,79	41	0,29	0,24
11	6,42	6,03	42	22,32	20,49
12	0,14	0,18	43	0,11	0,10
13	0,19	0,33	44	7,31	9,88
14	29,48	27,58	45	0,09	0,12
15	0,09	0,08	46	0,08	0,08
16	2,20	1,58	47	0,06	0,05
17	6,55	6,40	48	0,53	0,35
18	0,27	0,32	49	43,45	32,14
19	0,06	0,06	50	0,08	0,06
20	0,08	0,07	51	6,42	8,82
21	0,48	0,41	52	0,12	0,32
22	27,40	24,57	53	0,09	0,10
23	0,07	0,05	54	0,05	0,06
24	2,35	1,46	55	0,06	0,05
25	5,22	4,95	56	31,56	28,90
26	0,15	0,17	57	0,76	0,77
27	0,07	0,05	58	0,05	0,05
28	0,27	0,34	59	4,40	10,79
29	19,68	19,50	60	0,09	0,12

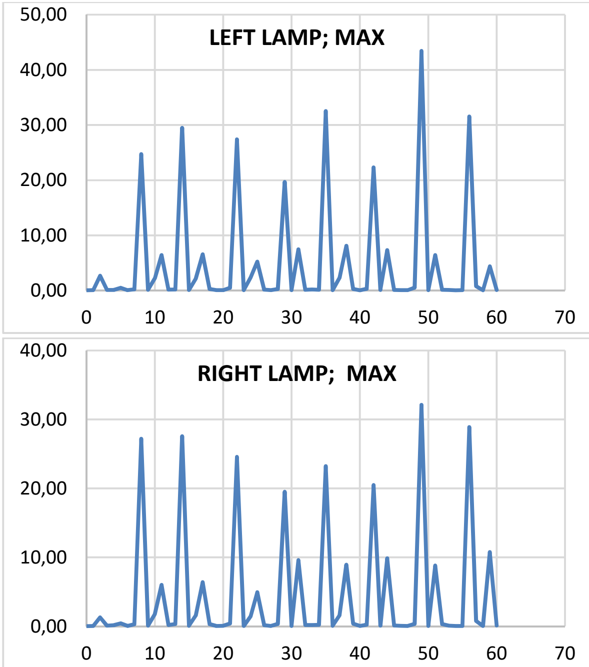

Fig. 7 Acceleration measurement - passenger car, misuse closing

TABLE VII
ACCELERATION MEASUREMENT - LCV CAR, MISUSE CLOSING

Time	Left lamp; max	Right lamp; max	Time	Left lamp; max	Right lamp; max
s	g	g	s	g	g
0	0,06	0,05	31	0,05	0,05
1	0,05	0,05	32	0,21	0,21
2	2,17	1,48	33	39,03	48,76
3	5,93	8,57	34	0,05	0,06
4	0,82	1,14	35	0,24	0,21
5	0,06	0,06	36	5,25	6,47
6	0,26	0,31	37	0,08	0,09
7	40,19	29,84	38	0,22	0,22
8	0,07	0,09	39	0,06	0,05
9	2,55	1,51	40	0,05	0,06
10	4,41	6,17	41	44,86	48,76
11	0,19	0,22	42	12,86	8,57
12	0,06	0,05	43	0,07	0,06
13	0,36	0,36	44	2,54	1,35
14	46,44	48,76	45	8,07	10,73
15	0,12	0,08	46	0,26	0,30
16	0,04	0,04	47	0,06	0,05
17	0,09	0,07	48	0,11	0,16
18	0,05	0,05	49	31,34	36,69
19	3,43	5,51	50	0,10	0,25
20	0,73	2,06	51	2,59	1,72
21	0,22	0,23	52	4,53	7,30
22	0,06	0,06	53	0,16	0,26
23	0,07	0,07	54	0,06	0,06
24	0,38	0,29	55	0,05	0,06
25	36,63	48,76	56	0,06	0,06
26	0,16	0,19	57	0,06	0,05
27	4,49	10,82	58	0,33	0,36
28	0,07	0,08	59	43,54	39,05
29	0,22	0,20	60	0,07	0,05
30	0,05	0,06			

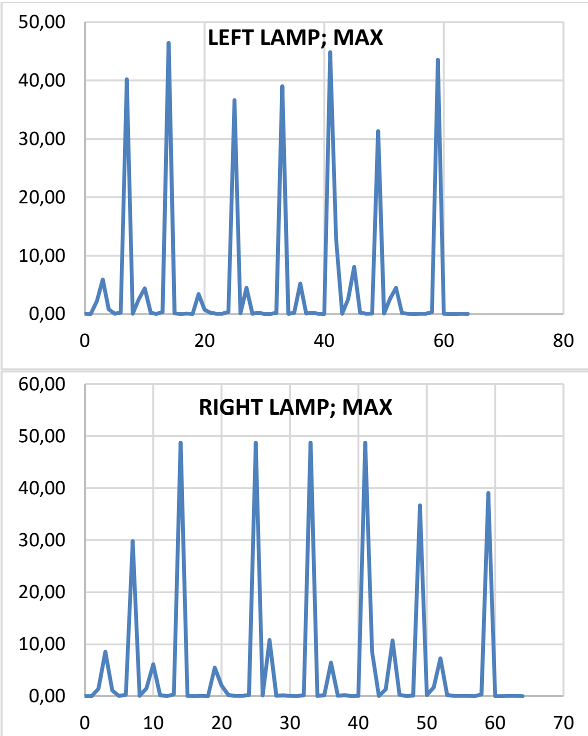

Fig. 8 Acceleration measurement - LCV Car, misuse closing

V. Experimental Results and Discussion

When the results of the voltage measurement experiments were examined, the first point of attention was the fact that the values between the right and left functions of the vehicle differed. When the electrical cable structure of the vehicle was examined, it was observed that the cable harnesses leading to the right functions of the vehicle were shorter compared to the left cable harnesses. It was therefore confirmed that the voltage values on the bulbs of the right lighting functions were lower. When the technical data sheets of the bulbs are examined, the correlation between voltage and bulb lives can be seen (Fig. 9).

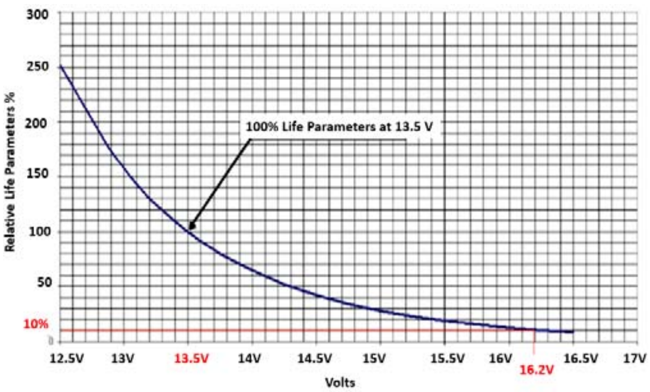

Fig. 9 Voltage and bulb life curve

All bulb manufacturers test their bulbs under a nominal voltage value of 13.5 Volts. When the voltage on the bulb increases, its lifespan decreases although its intensity of illumination increases. For this reason, the life of the bulb can be extended by achieving an intensity of illumination required in international regulations even in low voltages due to the best possible lighting design.

It was seen in acceleration measurement experiments that the effect of vehicle architecture on the vibration on the bulbs is a very important factor. The difference in static forces between the opening and closing of the 5th door of the passenger cars and the LCV cars was revealed in the experiments conducted. Bulb manufacturers verify that bulbs can withstand a maximum acceleration of 50g. Considering misuse, the stress that accumulates on the filament would cause the filament to fracture in a very short time. When the Figs. 5-8 are examined, it is seen that the vibration peaks 6 times in 1 second and this causes the filament to be fatigued.

During the production process of bulbs, internal impacts (stress, foreign substances etc.) can be created (Fig. 10). This accumulated stress causes the bulb filament to fracture before the guaranteed time with the vibrations it endures during bulb use. For this reason, the methods that would expose lighting functions to the least vibration should be considered in vehicle design.

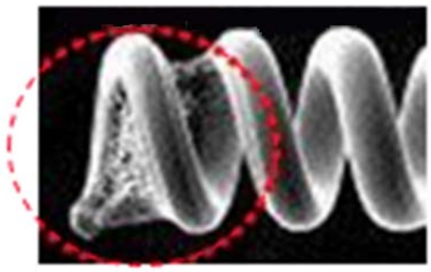

Fig. 10 Attached foreign substance on broken filament surface

As a result of the researches and experiments, it was observed that the lifespans of the bulbs on the lighting functions were shorter compared to the ones that endure high voltage. It was emphasized at the end of this study that when designing the vehicle architecture, optimum efficiency should be achieved by keeping the lengths of the cables that lead to the functions as short as possible and that bulb voltages should be reduced by making the optical designs of the functions in the most faultless way.

Another result of this study is that the boundary diagrams of the vehicle lighting lamps were considered and the vibrations towards the bulbs were minimized as a result of the interactions with the surrounding parts.

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