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MULTI OBJECTIVE OPTIMIZATION OF POWDER MIXED EDM PARAMETERS THROUGH MTOPSIS AND GRA

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Abstract - Electric Discharge Machining is extensively used for the manufacturing of different components including complex shapes on the normal materials and even on the hardened materials like ceramics, super alloys and steels. Considerable work has been done on the EDM in different aspects. Here, in this research paper Titanium alloy has been tested to determine the response parameters like MRR, TWR & SR when an additive is mixed in the dielectric fluid. Taguchi L27 has been selected and experiments were conducted to determine the response parameters and then multi objective optimization has been done using Modified TOPSIS and Grey Relational Analysis.

Key Words-GRA, Euclidean distance, MTOPSIS, GRC & Pi

I. Introduction

In Powder Mixed EDM suitable material in the form of powder will be mixed into the dielectric fluid in tank. For better circulation of the dielectric fluid a stirring system is used. The constant reuse of powder in the dielectric fluid can be done by the special circulation system. Various powders of particle can be added into the dielectric fluid. Spark gap provided by the additives particles. The powder particles of the material get energized & behave like a zigzag way manner. under the sparking zone, the particles of the material powder comes close to each other & arrange themselves in the form of chain like structure between the workpiece surface & tool electrode. The interlocking between the different powder particles occurs in the direction of flow current. The chain formation helps in bridging the discharge gap between the electrodes. Because of bridging effect, the insulating strength of the dielectric fluid decreases resulting in easy short circuit. This causes early explosion in the gap and series discharge' starts under the electrode area.

When voltage is applied the powder particles become energized and behave in a zigzag fashion. These charged particles are accelerated due to the electric field and act as conductors promoting breakdown in the gap. This increases the spark gap between tool and the work piece. Under the sparking area, these particles come close to each other and arrange themselves in the form of chain like structures. The faster sparking within a discharge causes faster erosion from the work piece surface and hence the material removal rate increases.

Parameters of this machine are mainly classified into two categories i.e. Process Parameters &Performance Parameters. The process parameters in EDM are used to control the performance measures of the machining process. Process parameters are generally controllable machining input factors that determine the conditions in which machining is carried out. These machining conditions will affect the process performance result, which are gauged using various performance measures. Performance Parameters These parameters measure the various process performances of EDM results.

II. Literature Survey:

PMEDM is extended usage of EDM, where some selected powders are mixed in dielectric fluid for the better results of the response parameters. The floating particles impede the ignition process by creating a higher discharge probability and lowering the breakdown strength of the insulating dielectric fluid. As a result, MRRis increased, TWR and SR are lowered due to the improvement in sparking efficiency.

In 2008 Kang and Kim studied EDM in order to investigate the effects of EDM process conditions on the crack susceptibility of a nickel based super alloy revealed that depending on the dielectric fluid and the post-EDM process such as solution heat treatment, cracks exist in recast layer could propagate into substrate when a 20% strain tensile force was applied at room temperature [1]. When kerosene as dielectric, it was observed that carburization and sharp crack propagation along the grain boundary occurred after the heat treatment. However, using deionized water as dielectric the specimen after heat treatment underwent oxidation and showed no crack propagation behaviour

In the same year Han-Ming Chow and other scientist investigated the effect of using pure water and a SiC powder for titanium (Ti) alloy in micro-slit EDM, and found that by using pure water as an EDM dielectric fluid for titanium alloy yields a high MRR and relatively low electrode wear and small expanding-slit by employing negative polarity (NP) processes [2]. Pure water and a SiC powder cause high conductivity; therefore, the gap was

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larger than using pure water in the EDM processes. Pure water and a SiC powder could disperse the discharging energy that refines the surface roughness effectively and also attains a higher MRR simultaneously than that of pure water.

Azad et al. [3] optimized multiple performances of micro-EDM process parameters for a set of target performances when Ti-6Al-4V is EDMed. It has been revealed that the most influential factors are voltage and current in the optimization of single quality characteristics. These factors are not influential in multiple quality characteristics. The predicted optimum condition has been verified experimentally. Ekmekci et al. [4] investigated the effect SiC powder added dielectric fluid on surface modification by using SEM and EDX analysis of plastic mould steel. They used dielectric fluid as tap water and mixed SiC particles at various conditions. Experiments were conducted in parametrical order; the investigated input parameters are discharge current, pulse on duration and concentration of SiC particles and electrolytic copper as electrode material with reverse polarity. It has been concluded that high discharge current and low pulse on duration conditions are well suitable for the tap water mixed SiC particles dielectric fluid.

Zakaria et al. [5] studied the effect of tantalum carbide (TaC) powder mixed dielectric fluid on EDM of SUS 304 steel. Pure copper electrode was employed with straight polarity. The TaC powder mixed (25g/L) in kerosene was used as a dielectric fluid. The process parameters are discharge current, pulse on time and pulse off time on the measured performance characteristics like micro-hardness and corrosion characteristics. It has been observed that as the discharge current increases, micro-hardness is decreased. They concluded that TaC powder added kerosene can increase the corrosion resistance of workpiece rather than compared it without addition of TaC powder. Rajiv Kumar Sharma et al. [6] optimized PMEDM process parameters while machining of cobalt-bonded tungsten carbide with electrolytic copper. GRA-Taguchi method was applied to optimise the multi-performance characteristics of micro-hardness and SR. The measured input process parameters are pulse on time, pulse off time, discharge current, and powders. They observed that the analytical and experimental results indicated the most significant parameters as powder, pulse on time and discharge current.

Murahri et al. [7-10] conducted experiments on the addition of surfactant and surfactant with graphite and B4C powder into the dielectric fluid and compare the results with without the addition of surfactant into the dielectric fluid while machining of Ti-6Al4V using modified EDM process. It has been observed that, surfactant with graphite powder addition into the dielectric fluid show better performance compared to that of B4C powder addition. Although the influence of various dielectrics onthe stability of electrical discharge machining of titanium alloy has been studied extensively, including the material removal, surface roughness and recast layer thickness and the profile of the work piece and electrode to the best of our knowledge, there is little work reported in open literature regarding the use of drinking water as dielectric fluid for EDM of Titanium alloy. Ramarao et al. [11] has conducted around 30 experiments to determine the permissible range of input parameters to fit it into the orthogonal array which is to be considered for the main experiment. They have considered MRR, TWR and SR as the performance measures for their trail experiments.

Here in this research paper, Titanium grade V material has been considered for making indentations along with the copper tool material, where drinking water is as the dielectric fluid. Orthogonal array L27 has been selected from the design of experiment for the response parameters MRR, TWR and SR. Multi objective optimization techniques i.e. MTOPSIS and GRA were applied separately to analyse and determine one set for the better values of the three response parametric combination.

III. Experimentation

A. Selection of workpiece material

Here, the material of the workpiece is Ti-6Al-4V alloy. The size of the workpiece is of the dimensions - length 100 mm, width 50 mm and thickness 5 mm. Murahari Kolli et al. [7-10] described the properties of the titanium alloy and are presented in below Table 1.

Table1: Properties of Titanium alloy

Property	Values
Hardness (HRC)	32-34
Melting point ($^{\circ}$C)	1649-1660
Density (g/cm^3)	4.43
Ultimate tensile strength (MPa)	897-950
Thermal conductivity (W/m K)	6.7-6.9
Specific heat (J/kgK)	560
Mean coefficient of thermal expansion (W/kg K)	8.6x10^{-6}
Volume electrical resistivity (ohm-cm)	170
Elastic Modulus (GPa)	113-114

B. Selection of the dielectric:

Drinking Water

Even though many dielectric fluids are available for the study of EDM, water is selected as the dielectric fluid here because it is environmental friendly. Drinking water is colorless, odorless, harmless, and easily available. The specifications of Drinking water is listed in Table 2 below.

Table 2: Specifications of Drinking water

Characteristic	Value
Appearance	White / Almost colourless
Odour	None
Density	0.9998 g/ml
Specific Gravity	1
Boiling point	99.98^{0}C
Flash Point (0^0C)	Non-Flammable
Thermal conductivity	0.6065 W/m·K
Viscosity	0.890
Copper corrosion	Almost zero (2.5 µm/year)
Conductivity	5-50 mS/m
Dielectric strength	60-70 v/m

C. Process Parameters

The values of the EDM parameters with levels are presented below in the Table 3.

Table 3: Process parameters with their levels

Parameter	Units	L1	L2	L3
Discharge current	Amp	10	15	20
Pulse ON time	µs	25	45	65
Pulse OFF Time	µs	24	36	48
Powder concentration	g/lit	5	10	15

D. Performance Measures

The performance measures considered here for the evaluation are Material Removal Rate (MRR), Tool Wear Rate (TWR), and Surface Roughness (SR). They are calculated using the following formulae,

Material Removal Rate (MRR)

The Material Removal Rate is calculated based on the workpiece weight loss for a particular time period and the relevant equation is given below,

$$\text{Material Removal Rate,MRR} = [\frac{(\mathrm{Wi-Wf})}{(\mathrm{D\ X\ t})}]\ \mathrm{X}\ 1000$$

W_i = Initial Weight in grams; W_f=Final Weight in grams

D=Density of the workpiece material in gm / cm^3

t = Time Period of the experiment in minutes

Units of MRR is mm^3/min

Tool Wear Rate (TWR)

TWR is calculated on the basis of the material lost by the tool during the process, based on the change of weight of the tool material before and after the machining process which is shown in the below equation,

$$\text{Tool Wear Rate,TWR} = \left[\frac{(\mathrm{T_i - T_f})}{(\mathrm{D\ X\ t})}\right] \mathrm{X}\ 1000$$

T_i = Initial Weight in grams: T_f=Final Weight in grams

Surface Roughness (SR)

The third machining parameter is surface roughness, SR. This measurement can be performed by using Talysurf, a portable type profilometer, in terms of Ra. Orthogonal array for L27 was obtained using MINITAB17.

E. Determination of preferred values through MTOPSIS

Determination of Weights using Standard Deviation Method

The weights of machining parameters can be calculated using the Standard deviation method through the formula given below:

$$\mathrm{Wj} = \frac{\sigma \mathrm{j}}{\sum_{\mathrm{k}=1}^{\mathrm{M}} \sigma \mathrm{j}}$$

Where W_j = Weights of the attributes

σj = Standard Deviation

M = Number of Values

To find out the weights of the attributes, first it is required to find out the average of the each machining parameter, i.e., MRR, TWR& SR (X_{AVE}). And then, the average value of the machining parameter is subtracted from each value of the machining parameter ($X-X_{AVE}$). Calculation of the average values of the machining parameters along with the output of the subtracted values, i.e., $X-X_{AVE}$ of the three machining parameters are calculated. The weights obtained are 0.6049 is for MRR and 0.0919 is for TWR and 0.3030 is for SR.

F. Analysis using MTOPSIS

This method was developed during 1981 by Hwang and Yoon. This concept is based on the selection of ideal solution and is done with the shortest Euclidean distance and the farthest distance from the wrong solution. This gives the best solution from the available alternatives. Firstly normalisation can be done and then, the square roots of the sum of squares of each parameter are calculated, which is used to divide each value to obtain normalized values.

Subsequently, R+ and R- of each machining parameter should be calculated. As we know, the material removal rate is the beneficial attribute and Tool wear rate along with the surface roughness are non-beneficial attributes. The values of ($R-R^+$) and ($R-R^-$) of each parameter are calculated which is called as normalised decision matrix. After obtaining the values of D+ and D-, the next immediate task is to find out the values of relative closeness Pi using the following formula and results are tabulated in the below Tables 4-6.

$$P_i = D^- / (D^+ + D^-)$$

Table 4: Calculation of Pi - 1

MRR		TWR		SR	
D+	**D-**	**D+**	**D-**	**D+**	**D-**
w(R-R+)^2	**w(R-R-)^2**	**w(R-R+)^2**	**w(R-R-)^2**	**w(R-R+)^2**	**w(R-R-)^2**
0.0218	0.0010	0.0003	0.0060	0.0017	0.0069
0.0301	0.0000	0.0001	0.0071	0.0055	0.0026
0.0246	0.0005	0.0006	0.0051	0.0002	0.0124
0.0196	0.0015	0.0000	0.0085	0.0075	0.0015
0.0298	0.0000	0.0001	0.0074	0.0052	0.0028
0.0252	0.0004	0.0000	0.0091	0.0015	0.0074
0.0251	0.0004	0.0000	0.0081	0.0012	0.0080
0.0321	0.0000	0.0000	0.0079	0.0015	0.0073
0.0252	0.0004	0.0000	0.0084	0.0005	0.0104
0.0077	0.0084	0.0040	0.0011	0.0058	0.0024
0.0168	0.0024	0.0033	0.0015	0.0029	0.0050
0.0118	0.0050	0.0028	0.0018	0.0003	0.0113
0.0098	0.0064	0.0014	0.0033	0.0056	0.0025
0.0149	0.0033	0.0014	0.0033	0.0092	0.0008
0.0094	0.0067	0.0014	0.0034	0.0039	0.0039
0.0086	0.0075	0.0022	0.0024	0.0016	0.0072
0.0181	0.0020	0.0016	0.0037	0.0043	0.0035
0.0147	0.0034	0.0013	0.0035	0.0000	0.0156
0.0001	0.0285	0.0091	0.0000	0.0042	0.0036
0.0010	0.0216	0.0072	0.0001	0.0064	0.0020
0.0001	0.0281	0.0071	0.0001	0.0019	0.0067
0.0001	0.0282	0.0061	0.0003	0.0078	0.0013
0.0020	0.0182	0.0059	0.0003	0.0156	0.0000
0.0009	0.0224	0.0052	0.0005	0.0035	0.0043
0.0000	0.0321	0.0066	0.0002	0.0055	0.0026
0.0024	0.0171	0.0062	0.0003	0.0048	0.0031
0.0009	0.0221	0.0047	0.0007	0.0003	0.0118

Table 5: Calculation of Pi - 2

Sum		Sqrt		
D+	**D-**	**D+**	**D-**	**Pi**
0.0239	0.0139	0.1546	0.1180	0.4330
0.0357	0.0098	0.1890	0.0988	0.3433
0.0253	0.0180	0.1592	0.1342	0.4575
0.0271	0.0115	0.1647	0.1072	0.3944
0.0350	0.0102	0.1871	0.1011	0.3508
0.0267	0.0170	0.1635	0.1303	0.4435
0.0264	0.0166	0.1625	0.1289	0.4423
0.0337	0.0152	0.1836	0.1235	0.4021
0.0258	0.0192	0.1605	0.1387	0.4635
0.0174	0.0119	0.1320	0.1089	0.4520
0.0230	0.0089	0.1518	0.0944	0.3835
0.0150	0.0181	0.1225	0.1344	0.5231
0.0169	0.0122	0.1300	0.1105	0.4594
0.0256	0.0074	0.1600	0.0861	0.3498
0.0147	0.0140	0.1213	0.1185	0.4941
0.0124	0.0171	0.1112	0.1307	0.5402
0.0240	0.0092	0.1549	0.0961	0.3827
0.0160	0.0225	0.1264	0.1499	0.5426
0.0135	0.0321	0.1162	0.1791	0.6066
0.0146	0.0237	0.1206	0.1540	0.5608
0.0091	0.0349	0.0953	0.1869	0.6624
0.0141	0.0298	0.1187	0.1727	0.5927
0.0235	0.0185	0.1532	0.1361	0.4705
0.0096	0.0272	0.0981	0.1650	0.6272
0.0121	0.0349	0.1101	0.1868	0.6292
0.0134	0.0204	0.1158	0.1429	0.5523
0.0059	0.0346	0.0771	0.1860	0.7070

Table6: Descending order of relative closeness

Rank No	Pi	Run No
1	**0.7070**	**27**
2	0.6624	21
3	0.6292	25
4	0.6272	24

5	0.6066	19
6	0.5927	22
7	0.5608	20
8	0.5523	26
9	0.5426	18
10	0.5402	16
11	0.5231	12
12	0.4941	15
13	0.4705	23
14	0.4635	9
15	0.4594	13
16	0.4575	3
17	0.4520	10
18	0.4435	6
19	0.4423	7
20	0.4330	1
21	0.4021	8
22	0.3944	4
23	0.3835	11
24	0.3827	17
25	0.3508	5
26	0.3498	14
27	0.3433	2

As per the result obtained from the above table, it is very clear that the relative closeness value is high for 27th run of the L_{27} orthogonal array which means the set values belongs to that run are the optimized set of values for the out puts considered.

The relative closeness is 0.7070 which is maximum among all the remaining values for the 27th run of the design of experiments which are conducted here. The relevant values of the 27th run are Discharge current is 20 Amp, Pulse ON time is 65 µs, Pulse OFF time is 48 µs, and Powder concentration is 10 g/lit.

G. Analysis using GRA:

The optimization related to the problem having more than one objective function is called Multi objective optimization. This is the area where more than two objective functions are solved simultaneously. Here in this section, there are three performance measures are considered such as MRR, TWR,and SR for the characterization of EDM.

Grey Relational Analysis is measurement method in the theory of the grey system which analyses the information required (uncertain & insufficient) between one factor and the remaining in the given system.

In this section, the methodology of the grey relational analysis is discussed and solved the Taguchi problem which was done in the previous. This kind of optimization i.e. multi-objective optimization can be performed as follows,

1. Obtain the data with machining parameters which are decided to have into the problem i.e. MRR, TWR, and SR.
2. Obtain the S/N ratios of the machining parameters using MINITAB 17. To obtain the S/N ratios, ‘Larger the better’ may be used for Material Removal Rate and ‘Smaller the better’ for the remaining two.
3. Normalize the S/N ratios using the relevant formulas.
4. Obtain the deviational sequences.
5. Determine the grey relational coefficient for the each machining parameter.
6. Calculate the average Grey relational coefficient and form in the descending order.
7. The set of values with high grey relational coefficient is the optimized set here. Table 7 & 8 shows the average grey relational coefficient of all the experiments.

Table 7: Calculation of S/N ratios

No	A	B	C	D	S/N ratios		
					MRR	TWR	SR
1	10	25	24	5	9.3038	12.6753	-9.9020
2	10	25	36	10	5.8065	15.4012	-12.6323
3	10	25	48	15	11.2251	8.5705	-6.1014
4	10	45	24	10	12.8894	19.1564	-13.1287
5	10	45	36	15	5.9591	16.1431	-12.0899
6	10	45	48	5	7.6468	23.5045	-9.2062
7	10	65	24	15	7.6745	19.1485	-9.2198
8	10	65	36	5	8.3421	18.2799	-9.6609
9	10	65	48	10	7.6436	20.1755	-7.7439
10	15	25	24	5	13.3131	3.2887	-12.7840
11	15	25	36	10	13.7609	2.0398	-10.6721
12	15	25	48	15	11.9712	2.6154	-6.8196
13	15	45	24	10	12.6008	6.9764	-12.3198

14	15	45	36	15	11.0129	5.2307	-13.7295
15	15	45	48	5	12.7310	5.4329	-11.7641
16	15	65	24	15	13.0093	3.6262	-9.7317
17	15	65	36	5	10.0124	5.9566	-12.0116
18	15	65	48	10	11.0946	5.5671	-4.2336
19	20	25	24	5	16.9417	-0.3798	-11.5792
20	20	25	36	10	16.0522	0.6294	-12.6580
21	20	25	48	15	16.8976	0.6650	-9.6478
22	20	45	24	10	20.2583	1.2607	-13.2508
23	20	45	36	15	15.5234	1.3973	-15.3312
24	20	45	48	5	16.1729	1.9122	-13.8153
25	20	65	24	15	17.3311	0.9500	-14.9588
26	20	65	36	5	15.3347	-0.5625	-14.6111
27	20	65	48	10	19.4776	0.5439	-9.1891

Table 8: Avg GRC values

Deviation sequences			Grey rel. coefficient			Avg. GRC
MRR	TWR	SR	MRR	TWR	SR	
0.7580	0.5500	0.4892	0.3975	0.4762	0.5054	0.4597
1.0000	0.6633	0.2432	0.3333	0.4298	0.6728	0.4786
0.6251	0.3795	0.8317	0.4444	0.5685	0.3755	0.4628
0.5099	0.8193	0.1985	0.4951	0.3790	0.7158	0.5300
0.9894	0.6941	0.2921	0.3357	0.4187	0.6313	0.4619
0.8727	1.0000	0.5519	0.3643	0.3333	0.4753	0.3910
0.8707	0.8190	0.5507	0.3648	0.3791	0.4759	0.4066
0.8245	0.7829	0.5110	0.3775	0.3897	0.4946	0.4206
0.8729	0.8617	0.6837	0.3642	0.3672	0.4224	0.3846
0.4806	0.1600	0.2295	0.5099	0.7576	0.6854	0.6509
0.4496	0.1081	0.4198	0.5265	0.8222	0.5436	0.6308
0.5734	0.1320	0.7670	0.4658	0.7911	0.3946	0.5505
0.5299	0.3132	0.2714	0.4855	0.6148	0.6482	0.5828
0.6397	0.2407	0.1443	0.4387	0.6750	0.7760	0.6299
0.5209	0.2491	0.3214	0.4898	0.6675	0.6087	0.5886
0.5016	0.1740	0.5046	0.4992	0.7418	0.4977	0.5796
0.7090	0.2709	0.2991	0.4136	0.6486	0.6257	0.5626
0.6341	0.2547	1.0000	0.4409	0.6625	0.3333	0.4789
0.2295	0.0076	0.3381	0.6854	0.9850	0.5966	0.7557
0.2910	0.0495	0.2409	0.6321	0.9099	0.6749	0.7389
0.2325	0.0510	0.5121	0.6826	0.9074	0.4940	0.6947
0.0000	0.0758	0.1875	1.0000	0.8684	0.7273	0.8652
0.3276	0.0814	0.0000	0.6041	0.8599	1.0000	0.8214
0.2827	0.1028	0.1366	0.6388	0.8294	0.7854	0.7512
0.2026	0.0628	0.0336	0.7117	0.8883	0.9371	0.8457
0.3407	0.0000	0.0649	0.5947	1.0000	0.8851	0.8266
0.0540	0.0460	0.5535	0.9025	0.9158	0.4746	0.7643

The grey relational coefficient of 0.8652 which is maximum among all the remaining values for the 22nd run of the design of experiments which are conducted here. The relevant values of the 22nd run are Discharge current is 20 Amp, Pulse ON time is 45 µs, Pulse OFF time is 24 µs, and Powder concentration is 10 g/lit.

IV. Results

According to the requirement of the response parameter values,the method GRA is preferable in comparison with the method MTOPSIS. The deviation of MTOPSIS results are compared with GRA and is found that MRR is 8.6%, TWR is -8.6% and SR is 37.35%. The graphical representation of the deviation is shown below separately in Fig 1 to Fig 3 for MRR, TWR and SR.

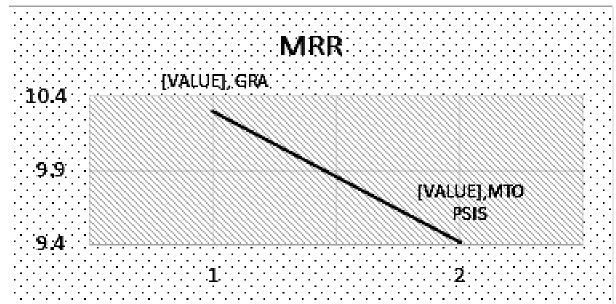

Fig 1: Deviation - MRR

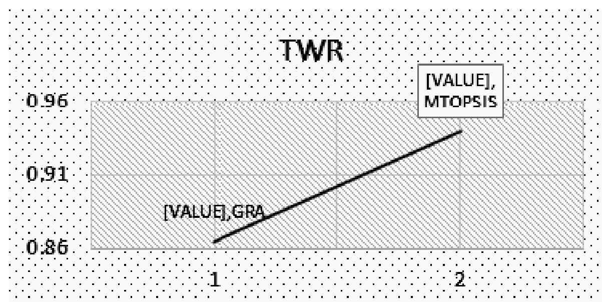

Fig 2: Deviation – TWR

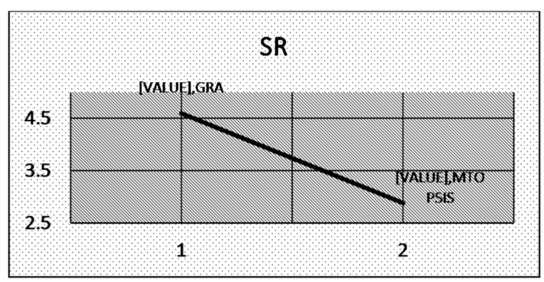

Fig 3: Deviation - SR

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