

Comparative Study of Differential Drives on The Basis of Operational Requirements by Use of Expert Rating Method

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Abstract – In a field of automobile sector, continuous development of various parts is carried out. The transmission system is a sensitive system of the automobile and in order to propagate vehicle forward, available power distribution plays vital role. There are many types of differentials available in market from which eleven types of differentials are studied in this paper. A panel of expert in the field of differential and transmission were invited to rate differentials on the basis of customer needs. All eleven differentials are compared to each other in order to find out maximum beneficial differential. Firstly the operational requirements are rated by expert and arranged in sequential manner then each expert has rated each differential. Lastly the differentials are arranged on the basis of total ratings. The electronic controlled differential works better than other mentioned differentials. This paper concludes that there are some differentials that can replace the simple differential with more benefits at the user end.

Key Words: Differential, Automobile, Wheels, Drive system, vehicle propulsion, two wheel Drive, Front axle, Rear axle, slippery track, off road conditions.

1. INTRODUCTION

There are several types of differentials used in transmission system of vehicle [1]. These differentials were developed from the birth of automobile industries. The construction and working of differentials differs from geographical conditions such as off-road demands four wheel drive, while all wheel drive is essential in winter falls [2]. Technically the differentials can be classified as mechanical, electronic or hybrid.

Now days, the vehicle are not limited only for passengers and transportation. A large verity of construction equipment and agricultural vehicles are developing in the world [3].

The space science and research demands differentials with no risk of failure hence, it is assumed to provide a comparative study of differential drives used today in automobile sector.

In this paper, various types of differentials are compared to each other. Especially simple differential, locking differential, spur or helical gear differential, limited slip differential, clutch pack differential, All wheel drive differential, Electronic controlled differential, Belt driven differential, CVT differential, Toroidal differential and

Differential locking by centrifugal action this eleven types of differential are compared with the following operational requirements [4].

2. OPERATIONAL REQUIREMENTS

The operational requirements are drawn from customer survey which is shown as below.

1. Constant power transmission.
2. Compatible with all types of vehicle.
3. Smooth operation in turn.
4. Work without human interface.
5. Balanced load on steering wheel.
6. Smooth operation in loaded conditions.
7. System performs lock-free operation.
8. Minimum turning radius assistance.
9. Speed recovery after turning.
10. Sensitive to speed variation.
11. System works when wheels are in the sand.
12. System works when wheels are in the mud.
13. System works when wheels are on the off-road conditions.
14. System works when vehicle climbs slope.
15. System works when wheels are on the slippery track.
16. System works when one wheel of vehicle is lifted up.

The above shown operational requirements are further used for rating of expert. Four experts from different work field are invited to rate firstly the operational requirement and then to rate the mentioned eleven types of differentials.

The expert designation and field of work is shown in table 1.

Table 1: Expert Panel

Expert Number	Name	Designation
1	A	Research and development department in automobile company from last 32 years.
2	B	Student of engineering Institute, and competitor of various events such as Mega ATV, SAE BAJA India, Enduro Student India.
3	C	Design Engineer, Automobile component developer company.
4	D	Product Developer, Differential Manufacturing Industry.

The above table shows experts and there designation. The operational requirement needs rating such that most important is rated with 10 points and least important is rated with 0 points.

Table 2: Rating of operational requirements given by experts

Sr. No.	Operational Requirements	Expert / Points				Total Out of 40
		A	B	C	D	
1.	System works when wheels are on the off-road conditions.	9	9	9	9	36
2.	System works when wheels are in the mud.	8	8	9	8	33
3.	System works when wheels are in the sand.	8	8	9	8	33
4.	System works when vehicle climbs slope.	8	9	8	8	33
5.	Compatible with all types of vehicle.	8	9	8	7	32
6.	Balanced load on steering wheel.	7	8	8	9	32
7.	System works when wheels are on the slippery track.	7	8	8	8	31
8.	System works when one wheel of vehicle is lifted up.	8	7	8	7	30

9.	Work without human interface.	8	8	6	7	29
10.	Minimum turning radius assistance.	7	8	7	7	29
11.	Smooth operation in loaded conditions.	7	7	7	7	28
12.	Sensitive to speed variation.	7	7	8	6	28
13.	Smooth operation in turn.	7	7	7	6	27
14.	Speed recovery after turning.	7	6	7	7	27
15.	Constant power transmission.	7	7	6	6	26
16.	System performs lock-free operation.	7	7	6	6	26

3. RATING OF DIFFERENTIALS BY EXPERTS

The following tables are essential to know proper sequence of customer satisfied differentials. Here operational requirements and rating of experts to particular differential are placed in columns and rows. The rating scale is 1 to 5 and meaning of these numbers is customer satisfaction. If it is difficult to choose a number then 0.5 rating can be added or subtracted from given number. All eleven differentials are rated as follows.

Table 3: Expert rating for simple differential

Sr. No.	Operational Requirements	Marks (M)	Expert Points (P)			
			A	B	C	D
1.	System works when wheels are on the off-road conditions.	36	2	2	2.5	2
2.	System works when wheels are in the mud.	33	2	2	2.5	2
3.	System works when wheels are in the sand.	33	2	2	2.5	2
4.	System works when vehicle climbs slope.	33	3	3	3	3
5.	Compatible with all types of vehicle.	32	4	4	4	4
6.	Balanced load on steering wheel.	32	4	3.5	3	3
7.	System works when wheels are on the slippery track.	31	1	1	1	1
8.	System works when one wheel of vehicle is lifted up.	30	1	1	1	1
9.	Work without human interface.	29	5	5	5	4.5
10.	Minimum turning radius assistance.	29	3	2.5	2.5	2
11.	Smooth operation in loaded conditions.	28	4	3.5	3	3

12.	Sensitive to speed variation.	28	4	4	4	4
13.	Smooth operation in turn.	27	4	4	4	4
14.	Speed recovery after turning.	27	4	4	4	4
15.	Constant power transmission.	26	4	2.5	2.5	2
16.	System performs lock-free operation.	26	5	4.5	4.5	2.5
Total Ratings $\sum M_n P_n$			1526	1429.5	1450.5	1357.5

Total Ratings $\sum M_n P_n$				1502	1383.5	1391	1295
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Table 4: Expert rating for spur/helical differential

Sr. No.	Operational Requirements	Marks (M)	Expert Points (P)			
			A	B	C	D
1.	System works when wheels are on the off-road conditions.	36	2	2	2.5	2
2.	System works when wheels are in the mud.	33	2	2	2.5	2
3.	System works when wheels are in the sand.	33	2	2	2.5	2
4.	System works when vehicle climbs slope.	33	3	3	3	3
5.	Compatible with all types of vehicle.	32	3	2.5	2.5	2
6.	Balanced load on steering wheel.	32	4	3.5	3	3
7.	System works when wheels are on the slippery track.	31	3	1.5	1.5	1.5
8.	System works when one wheel of vehicle is lifted up.	30	1	1	1	1
9.	Work without human interface.	29	5	5	5	4.5
10.	Minimum turning radius assistance.	29	3	2.5	2.5	2
11.	Smooth operation in loaded conditions.	28	4	4	4	4
12.	Sensitive to speed variation.	28	3	3.5	3	3
13.	Smooth operation in turn.	27	4	4	4	4
14.	Speed recovery after turning.	27	4	3.5	3	3
15.	Constant power transmission.	26	4	3	3	3
16.	System performs lock-free operation.	26	4	4	4	4
Total Ratings $\sum M_n P_n$			1749	1638.5	1639	1563

Table 5: Expert rating for locking differential

Sr. No.	Operational Requirements	Marks (M)	Expert Points (P)			
			A	B	C	D
1.	System works when wheels are on the off-road conditions.	36	5	4	4	4
2.	System works when wheels are in the mud.	33	5	4	4	4
3.	System works when wheels are in the sand.	33	5	4.5	4.5	4.5
4.	System works when vehicle climbs slope.	33	5	5	5	4.5
5.	Compatible with all types of vehicle.	32	2	2.5	2.5	2
6.	Balanced load on steering wheel.	32	4	4	4	4
7.	System works when wheels are on the slippery track.	31	5	4.5	4.5	4.5
8.	System works when one wheel of vehicle is lifted up.	30	5	5	5	4.5
9.	Work without human interface.	29	2	2.5	2.5	2
10.	Minimum turning radius assistance.	29	3	3	3	3
11.	Smooth operation in loaded conditions.	28	3	3	3	3
12.	Sensitive to speed variation.	28	2	2	2.5	2
13.	Smooth operation in turn.	27	2	1.5	1.5	1.5
14.	Speed recovery after turning.	27	4	3.5	3	3
15.	Constant power transmission.	26	3	3	3	3
16.	System performs lock-free operation.	26	2	3.5	1.5	1.5
Total Ratings $\sum M_n P_n$			1749	1638.5	1639	1563

Table 6: Expert rating for limited slip differential

Sr. No.	Operational Requirements	Marks (M)	Expert Points (P)			
			A	B	C	D
1.	System works when wheels are on the off-road	36	3	3	3	3

	conditions.					
2.	System works when wheels are in the mud.	33	3	3	3	3
3.	System works when wheels are in the sand.	33	3	3.5	3	3
4.	System works when vehicle climbs slope.	33	4	3.5	3	3
5.	Compatible with all types of vehicle.	32	3	3	3	3
6.	Balanced load on steering wheel.	32	3	3	3	3
7.	System works when wheels are on the slippery track.	31	4	4	4	4
8.	System works when one wheel of vehicle is lifted up.	30	3	3.5	3	3
9.	Work without human interface.	29	5	5	5	4.5
10.	Minimum turning radius assistance.	29	3	3	3	3
11.	Smooth operation in loaded conditions.	28	3	3	3	3
12.	Sensitive to speed variation.	28	3	2.5	2.5	2
13.	Smooth operation in turn.	27	4	4	4	4
14.	Speed recovery after turning.	27	4	4	4	4
15.	Constant power transmission.	26	4	3.5	3	3
16.	System performs lock-free operation.	26	4	4	4	4
Total Ratings $\sum M_n P_n$			1668	1656	1595	1566.5

Table 7: Expert rating for clutch pack differential

Sr. No.	Operational Requirements	Marks (M)	Expert Points (P)			
			A	B	C	D
1.	System works when wheels are on the off-road conditions.	36	4	3.5	3	3
2.	System works when wheels are in the mud.	33	4	4	4	4
3.	System works when wheels are in the sand.	33	4	4	4	4
4.	System works when vehicle climbs slope.	33	4	3.5	3	3
5.	Compatible with all types of vehicle.	32	2	2	2.5	2
6.	Balanced load on steering wheel.	32	3	3	3	3

7.	System works when wheels are on the slippery track.	31	4	4	4	4
8.	System works when one wheel of vehicle is lifted up.	30	5	5	5	4.5
9.	Work without human interface.	29	1	1	1	1
10.	Minimum turning radius assistance.	29	5	5	5	4.5
11.	Smooth operation in loaded conditions.	28	4	4	4	4
12.	Sensitive to speed variation.	28	3	2.5	2.5	2
13.	Smooth operation in turn.	27	2	2	2.5	2
14.	Speed recovery after turning.	27	2	2	2.5	2
15.	Constant power transmission.	26	2	2	2.5	2
16.	System performs lock-free operation.	26	2	1.5	1.5	1.5
Total Ratings $\sum M_n P_n$			1556	1494.5	1516	1416.5

Table 8: Expert rating for all wheel drive differential

Sr. No.	Operational Requirements	Marks (M)	Expert Points (P)			
			A	B	C	D
1.	System works when wheels are on the off-road conditions.	36	3	3	3	3
2.	System works when wheels are in the mud.	33	3	3	3	3
3.	System works when wheels are in the sand.	33	3	3	3	3
4.	System works when vehicle climbs slope.	33	4	4	4	4
5.	Compatible with all types of vehicle.	32	3	3.5	3	3
6.	Balanced load on steering wheel.	32	3	3	3	3
7.	System works when wheels are on the slippery track.	31	4	4	4	4
8.	System works when one wheel of vehicle is lifted up.	30	3	3	3	3
9.	Work without human interface.	29	5	5	5	4.5
10.	Minimum turning radius assistance.	29	3	3	3	3
11.	Smooth operation in loaded conditions.	28	4	4	4	4
12.	Sensitive to speed variation.	28	4	4	4	4

13.	Smooth operation in turn.	27	3	3	3	3
14.	Speed recovery after turning.	27	4	3.5	3	3
15.	Constant power transmission.	26	3	3	3	3
16.	System performs lock-free operation.	26	3	3	3	3
Total Ratings $\sum M_n P_n$			1645	1647.5	1618	1603.5

Table 9: Expert rating for electronic differential

Sr. No.	Operational Requirements	Marks (M)	Expert Points (P)			
			A	B	C	D
1.	System works when wheels are on the off-road conditions.	36	5	5	5	5
2.	System works when wheels are in the mud.	33	5	5	5	5
3.	System works when wheels are in the sand.	33	5	5	5	5
4.	System works when vehicle climbs slope.	33	5	5	5	5
5.	Compatible with all types of vehicle.	32	2	2	2.5	2
6.	Balanced load on steering wheel.	32	3	3.5	3	3
7.	System works when wheels are on the slippery track.	31	5	5	5	5
8.	System works when one wheel of vehicle is lifted up.	30	3	3	3	3
9.	Work without human interface.	29	5	5	5	5
10.	Minimum turning radius assistance.	29	4	4	4	4
11.	Smooth operation in loaded conditions.	28	3	3.5	3	3
12.	Sensitive to speed variation.	28	5	5	5	4.5
13.	Smooth operation in turn.	27	5	5	5	4.5
14.	Speed recovery after turning.	27	5	5	5	4.5
15.	Constant power transmission.	26	3	3	3	3
16.	System performs lock-free operation.	26	3	2.5	2.5	2
Total Ratings $\sum M_n P_n$			1991	2008	1994	1924

Table 10: Expert rating for belt driven differential

Sr. No.	Operational Requirements	Marks (M)	Expert Points (P)			
			A	B	C	D
1.	System works when wheels are on the off-road conditions.	36	2	2	2.5	2
2.	System works when wheels are in the mud.	33	2	1.5	1.5	1.5
3.	System works when wheels are in the sand.	33	2	2	2.5	2
4.	System works when vehicle climbs slope.	33	2	2	2.5	2
5.	Compatible with all types of vehicle.	32	2	2	2.5	2
6.	Balanced load on steering wheel.	32	3	3	3	3
7.	System works when wheels are on the slippery track.	31	2	2	2.5	2
8.	System works when one wheel of vehicle is lifted up.	30	1	1	1	1
9.	Work without human interface.	29	5	5	5	4.5
10.	Minimum turning radius assistance.	29	3	2.5	2.5	2
11.	Smooth operation in loaded conditions.	28	3	3	3	3
12.	Sensitive to speed variation.	28	3	2.5	2.5	2
13.	Smooth operation in turn.	27	3	3	3	3
14.	Speed recovery after turning.	27	3	2.5	2.5	2
15.	Constant power transmission.	26	3	3	3	3
16.	System performs lock-free operation.	26	4	4	4	4
Total Ratings $\sum M_n P_n$			1266	1207.5	1290	1151

Table 11: Expert rating for CVT differential

Sr. No.	Operational Requirements	Marks (M)	Expert Points (P)			
			A	B	C	D
1.	System works when wheels are on the off-road conditions.	36	2	2	2.5	2
2.	System works when wheels are in the mud.	33	2	2	2	2
3.	System works when wheels are in the sand.	33	2	2	2.5	2

4.	System works when vehicle climbs slope.	33	2	2	2.5	2
5.	Compatible with all types of vehicle.	32	2	2	1.5	2
6.	Balanced load on steering wheel.	32	2	2	2	2
7.	System works when wheels are on the slippery track.	31	2	2	2.5	2
8.	System works when one wheel of vehicle is lifted up.	30	1	1	1	1
9.	Work without human interface.	29	4	4	4	4
10.	Minimum turning radius assistance.	29	3	3	2.5	3
11.	Smooth operation in loaded conditions.	28	3	3	2.5	3
12.	Sensitive to speed variation.	28	2	2	1.5	2
13.	Smooth operation in turn.	27	2	2	1.5	2
14.	Speed recovery after turning.	27	2	2	2.5	2
15.	Constant power transmission.	26	2	2	2.5	2
16.	System performs lock-free operation.	26	4	4	3	4
Total Ratings $\sum M_n P_n$			1097	1097	1234	1097

10.	Minimum turning radius assistance.	29	2	2	2.5	2
11.	Smooth operation in loaded conditions.	28	2	2	2.5	2
12.	Sensitive to speed variation.	28	2	1.5	1.5	1.5
13.	Smooth operation in turn.	27	2	1.5	1.5	1.5
14.	Speed recovery after turning.	27	2	2	2.5	2
15.	Constant power transmission.	26	2	2	2.5	2
16.	System performs lock-free operation.	26	3	3	3	3
Total Ratings $\sum M_n P_n$			1014	970.5	1092	970.5

Table 13: Expert rating for differential locking by centrifugal action

Sr. No.	Operational Requirements	Marks (M)	Expert Points (P)			
			A	B	C	D
1.	System works when wheels are on the off-road conditions.	36	3	3	3	3
2.	System works when wheels are in the mud.	33	3	3	3	3
3.	System works when wheels are in the sand.	33	3	3.5	3	3
4.	System works when vehicle climbs slope.	33	4	3.5	3	3
5.	Compatible with all types of vehicle.	32	3	2.5	2.5	2
6.	Balanced load on steering wheel.	32	3	3	3	3
7.	System works when wheels are on the slippery track.	31	4	4	4	4
8.	System works when one wheel of vehicle is lifted up.	30	4	2.5	3	3
9.	Work without human interface.	29	5	5	5	4.5
10.	Minimum turning radius assistance.	29	3	3	3	3
11.	Smooth operation in loaded conditions.	28	2	3	3	3
12.	Sensitive to speed variation.	28	3	2.5	2.5	2
13.	Smooth operation in turn.	27	4	4	4	4
14.	Speed recovery after turning.	27	3	4	4	4
15.	Constant power transmission.	26	4	3.5	3	3

Table 12: Expert rating for toroidal differential

Sr. No.	Operational Requirements	Marks (M)	Expert Points (P)			
			A	B	C	D
1.	System works when wheels are on the off-road conditions.	36	2	2	2.5	2
2.	System works when wheels are in the mud.	33	2	2	2	2
3.	System works when wheels are in the sand.	33	2	2	2.5	2
4.	System works when vehicle climbs slope.	33	2	2	2.5	2
5.	Compatible with all types of vehicle.	32	2	1.5	1.5	1.5
6.	Balanced load on steering wheel.	32	2	2	2	2
7.	System works when wheels are on the slippery track.	31	2	2	2.5	2
8.	System works when one wheel of vehicle is lifted up.	30	1	1	1	1
9.	Work without human interface.	29	4	4	4	4

16.	System performs lock-free operation.	26	3	3.5	3	3
Total Ratings $\sum M_n P_n$		1266	1627	1553	1508.5	

Above tables 3 to 13 shows the strength of differential that can sustain various conditions mentioned in operational requirements. The highest total rating of any differential shows its highest strength and hence a table 14 is generated to show sequence of listed differentials according to expert ratings [5].

Table 14: Sequence of differential with relative importance by expert

Sr. No.	Differential type	Average of Total Ratings by A, B, C, D
1.	Electronic Controlled Differential.	1979.25
2.	Locking Differential.	1647.38
3.	All Wheel Drive Differential.	1628.50
4.	Limited Slip Differential.	1621.38
5.	Clutch Pack Differential.	1495.75
6.	Differential Locking by Centrifugal Action.	1488.63
7.	Simple Differential.	1440.88
8.	Spur Gear Differential.	1392.88
9.	Belt Driven Differential.	1228.63
10.	CVT Differential.	1131.25
11.	Toroidal Differential.	1011.75

4. CONCLUSION

Experts of transmission system have rated the mentioned differentials. The electronic controlled differential best suits to the operational requirements generated from customer needs. A typical simple differential achieved 7th place in the total ratings which provides better chances to improve it according to operational requirements. The locking differential achieved 2nd place which is derived from simple differential, hence the simple differential needs improvements in its design.

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