浙江科技学院学报，第25卷第1期，2013年2月
Journal of Zhejiang University of Science and Technology
Vol. 25 No. 1，Feb. 2013

doi：10.3969/j.issn.1671-8798.2013.01.012

轮胎磨损程度对在用车排放特性的影响研究

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摘　要： 采用VMAS排放检测系统作为实验平台，在同一辆实验车上换装不同磨损程度的轮胎进行排放检测。实验结果表明，随着在用车使用的时间增长，轮胎的磨损程度也随之增大，轮胎磨损后导致了轮胎与路面间摩擦力的显著降低，影响到车辆的动力性、经济性和牵引性能，对汽车的排放有直接的影响，特别是在变工况下影响尤为明显。通过实验，找出了轮胎磨损程度与汽车排放特性之间的关系，为控制在用车排放污染物提供了实验依据。

关键词： 汽车排放特性；轮胎；磨损程度；实验；计算分析

中图分类号： X734.2　　**文献标志码：** A　　**文章编号：** 1671-8798(2013)01-0059-08

Study on influence of tyre wear degree on emission characteristics of in-use vehicle

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Abstract： By using the VMAS emission detection system as the experiment platform，we can reload tyres with different wear degrees to implement emission detection. As the experiment results show，the wear degree of the tyre increases with the time growth of the vehicle in use，which results in that the friction force between the tyre and the road surface is significantly decreaced. As a result，the vehicle's performance，economy and traction performance are influenced，and there is also a direct influence on the vehicle emissions，especially in variable conditons. The study attempts to find out the relationship between the wear degree of the tyre and vehicle emission characteristics，which can provide an experimental evidence for controlling

收稿日期： 2013-01-05

基金项目： 山东省自然科学基金项目(ZR2009FM029)；山东省科技发展计划项目(2012GGB01152)

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the emission polution of the in-use vehicle.

Key words: characteristics of automobile emission; tyre; wear degree; experiment; computational analysis

轮胎与路面间的摩擦是一个非常复杂而且很重要的问题[1],轮胎的磨损程度直接影响到汽车的一些基本性能,如动力性、经济性等。随着磨损程度的加剧,对汽车排放的影响也是不容忽视的。轮胎与路面间的摩擦情况除路面因素外,主要受到滑移率、轮胎类型、胎面花纹和磨损程度等因素的影响。在其他因素一定的前提下,对既定车型来说,轮胎磨损程度对在用车的排放是一个重要的影响因素。本研究通过实验数据证实了该影响因素的实际意义。

1 汽车轮胎

汽车的驱动力是通过路面作用于驱动轮上的切向反力来获得的。这个切向反力是由驱动轮轮胎与地面接触产生摩擦而产生的,因此,在路面情况既定的前提下,轮胎的结构形式及磨损状况就成了影响驱动力的主要因素。轮胎磨损后,其静力半径和滚动半径将变小,同时轮胎与地面间的附着性能将变差,这不仅影响了汽车的基本性能,还直接影响到发动机应有性能的发挥,使得发动机在理论设计工况下不能与汽车的实际行驶工况相匹配,从而对汽车排放产生影响。

1.1 轮胎形式

目前,常用的汽车轮胎主要有子午线轮胎、斜交轮胎和带束斜交轮胎 3 种形式。子午线轮胎滚动阻力小,地面附着能力大;斜交轮胎滚动阻力大,地面附着能力小;带束斜交轮胎则介于二者之间。轮胎的结构要素对轮胎摩擦性能有着显著的影响,其结构要素主要包括胎面花纹形式、密度系数和花纹深度等 3 个方面[1]。胎面花纹可分为 3 类:纵向花纹(有较好的横向防滑能力)、横向花纹(有较好的纵向防滑能力)和块状花纹(纵向和横向均有较好的防滑能力)。

1.2 轮胎的变形

由于轮胎橡胶的弹性变形,对轮胎和路面间的摩擦力将产生一定的作用,这种作用是在轮胎设计过程中早已考虑到的,但是轮胎磨损后轮胎橡胶的弹性变形将发生变化,从而导致轮胎与路面间的摩擦力发生改变。这种关系的改变会直接影响到轮胎和路面间的滑移率和附着系数[2-3]。定义滑移率为 S_r,附着系数为 μ。

$$\mu = \frac{F_x}{F_z}, S_r = 1 - \frac{v}{r\omega} = \frac{v_s}{v_t}。 \tag{1}$$

式(1)中:F_x— 附着力;F_z— 垂直载荷;v— 车轮实际速度;v_t— 车辆的理论速度;v_s— 同一点绝对速度的切向分量;r— 节圆半径;ω— 驱动轮角速度。

理论上轮胎与地面间是无滑移的,也就是说滑移率为零。但是,汽车在行驶时要产生驱动力就必须依靠在纵向力的作用下,通过轮胎在与路面接触区域内的局部切向弹性变形来产生摩擦力,即附着力。显然,摩擦力产生的大小与产生切向弹性变形的区域面积有关,即与滑移率有关。

1.3 轮胎的磨损原因及磨损标志

轮胎产生磨损的原因很多,主要有轮胎气压过高或过低、车轮定位不正确、转向机构参数的改变、车轮动平衡不准、轮毂与轴承的间隙不符合要求和驾驶操作等方面[4]。

轮胎一般都在其胎冠的侧面标有指示磨损程度的记号,也就是磨损标志[5]。其功用是显示轮胎的使用限度,并指示轮胎花纹的残留深度。如果磨损超过该记号,车轮会打滑,应及时更换轮胎。

2 实验方法

本实验采用 VMAS 检测系统作为实验平台,实验车在检测平台上进行轮胎不同磨损程度的排放污染物的检测实验。

2.1　实验方法的确定

VMAS 检测系统是一种比较成熟的在用车排放污染物的实验检测系统，它与维修结合起来就是 I/M 制度，该制度在国内外均得到了广泛的认可和应用。本实验以 VMAS 系统作为实验平台，严格按照文献[6-7]规定的实验循环及相关要求对样车排放污染物进行检测，实验循环如图 1 所示。

实验样车采用正常使用的在用车，在实验过程中分别对样车更换磨损程度不同（新、中、旧）的轮胎，磨损程度用轮胎花纹深度表示。新轮胎花纹深度 9 mm，中度磨损轮胎花纹深度 5 mm，旧轮胎花纹深度 2 mm。每一种状态分别做 3 次实验，并取得实验数据。

实验结束后，对实验数据进行客观的分析研究，并用灰色系统理论对实验结果进行辅助分析和评价，从中找出其关联度。

2.2　实验所用的仪器设备及实验车基本信息

实验所用的仪器设备及实验车基本信息见表 1。检测日期为 2012 年 12 月 27 日。

表 1　实验设备及实验车辆信息

Table 1　Experimental facilities and information of vehicle

仪器设备及实验车	项目	信息
实验设备	系统编号	lgdx0053583
	检测工况	VMAS
	检测设备编号/认证码	QPS-1300/JSCT345RX
实验车辆	车辆品牌/型号	捷达/ FV7160FG
	车辆识别	LFV2A11G8C4032286
	排放标准	国 IV＋OBD
	车辆生产日期	2012-08-21
	车辆注册日期	2012-09-21
	行驶里程	2 000 km
	发动机型号/编号	BJT/56387
	供油方式	电喷
	进气方式	自然吸气
	轮胎规格	185/60 R14
	变速器型式	手动档

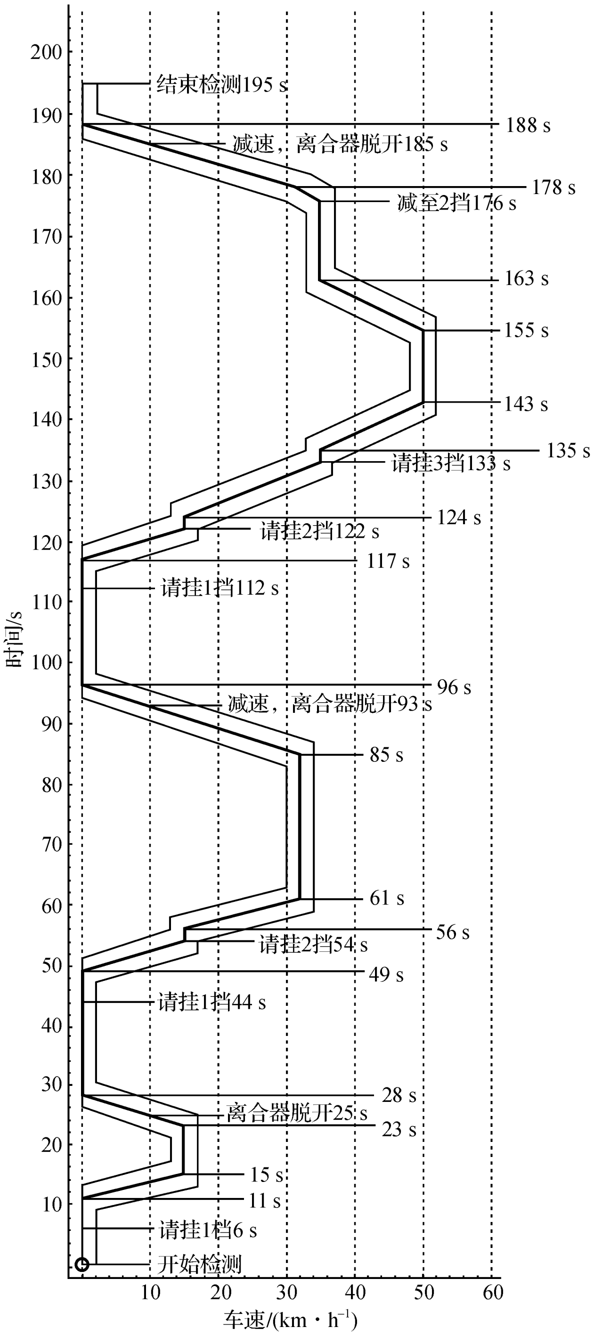


图 1　VMAS 实验循环图

Fig. 1　Experimental cycle diagram of VMAS

2.3　一般实验条件

实验在山东省淄博市机动车排放污染物检测中心进行。该中心实验场地及实验设备完全符合国家有关标准的要求，实验所用的仪器设备均经技术监督部门定期检验并合格。实验前用标准物质对仪器按文献[6]中的有关规定进行了标定。实验车辆的状态符合技术要求，发动机用 93 号汽油。实验时环境温度 0.3 ℃，相对湿度 30.7%，大气压力 103.5 kPa。

3　实验结果

3.1　采样点及数据

实验结果的数据由两部分组成，一部分是整个实验循环 195 s 的实验数据，取样频率为 1 s；另一部分是关键点的数据。由于 195 s 内的数据较多，本研究只分别给出了一次实验的关键点数据及对应的实验工况，如表 2 和表 3 所示。同样本研究也只给出了 CO 和 HC 的实验结果。195 s 实验循环（旧）实验数据的样本见图 2。

表 2 汽车排放实验结果

Table 2 Experimental result of vehicle emissions

取样时间点/s	CO(新)/%	HC(新)/ $\times 10^{-6}$	CO(中)/%	HC(中)/$\times 10^{-6}$	CO(旧)/%	HC(旧)/$\times 10^{-6}$
11	0.37	9.00	0.68	71.00	0.18	86.00
15	0.21	11.00	0.56	73.00	0.18	86.00
23	0.18	16.00	0.55	74.00	0.38	82.00
28	0.10	18.00	0.52	99.00	0.60	85.00
49	0.43	22.00	0.43	127.00	0.17	104.00
61	0.33	24.00	0.58	92.00	1.00	94.00
85	0.20	21.00	0.52	104.00	0.49	106.00
96	0.20	21.00	0.77	100.00	2.00	108.00
117	0.00	11.00	0.07	64.00	0.20	103.00
143	0.30	10.00	0.47	68.00	0.77	89.00
155	0.15	10.00	0.36	61.00	0.47	88.00
163	0.01	10.00	0.34	55.00	0.62	85.00
178	0.05	8.00	0.23	45.00	0.43	80.00
188	0.01	8.00	0.23	39.00	1.39	82.00
195	0.01	8.00	0.12	61.00	0.62	85.00

表 3 关键点对应的实验工况

Table 3 Experiment conditions corresponding with key points

取样时间点/s	工况	档位	速度/(km·h^{-1})	取样时间点/s	工况	档位	速度/(km·h^{-1})
11	起步	K1	0→15	117	起步	PM+K1	0→15→35→50
15	等速	K1		143	等速	3	
23	减速	1+K1	15→0	155	减速	3	50→35
28	怠速	空档		163	等速	3	
49	起步	PM+K1	0→15→32	178	减速	2+K2	35→10→0
61	等速	2		188	怠速	空档	
85	减速	2	32→10→0	196	怠速	空档	PM
96	怠速	空档					

注:1) K1,K2—变速器置 1 档或 2 档,离合器脱开;PM—变速器置空档,离合器结合。2)在关键点 49~61 之间 54 s 处换 2 档并加速至 61 s 等速;在关键点 85~96 之间 93 s 处离合器脱开并减速至 96 s 怠速;在关键点 117~143 之间 112 s 换 2 档加速,133 s 处换 3 档并加速到 143 s 处等速;在关键点 178~188 之间 185 s 处离合器脱开并减速至 188 s 怠速。资料来源:GB 18285—2005 点燃式发动机汽车排气污染物排放限值及测量方法。

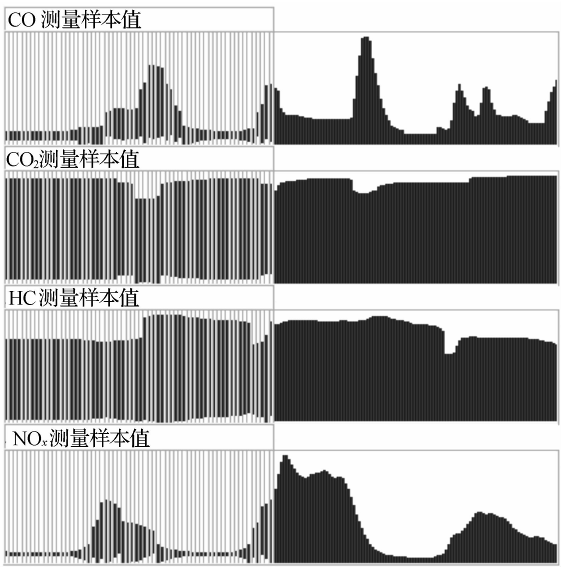


图 2 测量参数样本

Fig. 2 Samples of measurement parameters

3.2　实验结果及裁决

最终实验结果按国家有关标准的要求将计量单位均换算为 g/km，并将 HC 和 NO_x 合并为（HC+NO_x）作为一项判定指标[6-7]，实验结果及裁决见表 4。

表 4　结果及裁决

Table 4　Results and conclusions

排放污染物		检测结果/(g·km^{-1})	限值/(g·km^{-1})	判定结果	裁决结果
CO	新	1.71	9.20	合格	通过
	中	7.56	9.20	合格	通过
	旧	9.65	9.20	不合格	未能过
（HC+NO_x）	新	0.13	3.30	合格	通过
	中	1.50	3.30	合格	通过
	旧	1.44	3.30	合格	通过

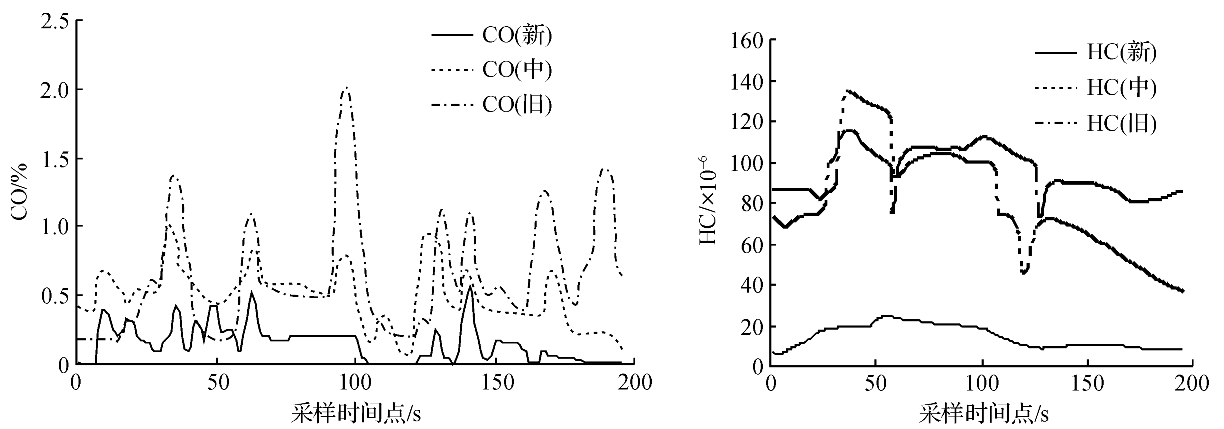
4　实验结果分析

从表 4 中可以看出，轮胎的磨损程度不同直接影响到了汽车排放，磨损严重（旧）的轮胎其排放的污染物超出了国家标准的限值而被裁决为不合格。

4.1　实验数据整理与分析

整个实验循环共计 195 s，采样频率为 1 s。但是在 0～11 s 起步前和 188～195 s 停车后时段车速为 0 km/h，以及实验循环中间的车速为 0 km/h 的时段可以不进行分析，因为此时车速为 0 km/h 的实验结果与轮胎磨损与否无关。

根据实验数据作出如图 3 所示的排放特性曲线，从实验结果曲线上看，轮胎磨损程度严重的旧轮胎排放特性明显比磨损程度较轻和几乎没有磨损的新轮胎差。另外，从表 5 给出的在变工况下排放数据的处理结果[8]也显示了同样的结论。但是，从图 3 和表 5 中发现了离散点的存在，离散点对应车速由 0→15 km/h换挡→32 km/h、采样点 49～61 时段内的工况，其特征表现为用旧轮胎测得的数据比用中度磨损的轮胎测得的数据小。分析认为，出现离散点的原因可能与车辆的操作有关，尽管车速没有超出 ±2 km/h的误差，但由于车速控制不稳而引起发动机工况的波动造成了排放的不稳定。轮胎磨损后对排放特性的影响是明显的，特别是汽车在加速、减速工况下轮胎磨损程度对其排放的影响尤为明显，排放特性随轮胎磨损程度的加剧变得越来越差。



(a) CO排放特性　　(b) HC排放特性

图 3　试验车的排放特性曲线

Fig. 3　Emission characteristic curve of test vehicle

表 5 变工况下排放数据平均值

Table 5 Average value of emissions in variable conditions

工况/(km·h^{-1})	CO(新)/%	HC(新)/×10^{-6}	CO(中)/%	HC(中)/×10^{-6}	CO(旧)/%	HC(旧)/×10^{-6}
车速由0→15	0.29	10.00	0.63	72.00	0.18	86.00
车速由15→0	0.14	17.00	0.54	73.50	0.49	83.50
车速由0→15换挡→32	0.38	20.00	0.51	109.50	0.14	99.00
车速由32→10→0	0.20	21.00	0.56	102.00	1.25	107.00
车速由0→15→35→50	0.15	10.50	0.27	66.00	1.39	96.00
车速由50→35	0.08	10.00	0.35	58.00	0.55	86.50
车速由35→10→0	0.03	8.00	0.23	42.00	0.91	81.00

工况/(km·h^{-1})	加权平均值		
	新	中	旧
车速由0→15	5.50	36.32	43.09
车速由15→0	8.57	37.02	42.00
车速由0→15换挡→32	10.19	55.01	49.57
车速由32→10→0	10.60	51.28	54.13
车速由0→15→35→50	5.33	33.14	48.70
车速由50→35	5.04	29.18	43.53
车速由35→10→0	4.02	21.12	40.96

注:1)车速由32→10→0 km/h是指:车速由32 km/h减速到10 km/h再在2档离合器脱开减速到0 km/h;2)车速由0→15→35→50 km/h是指:车速由0 km/h加速到15 km/h换2档加速到35 km/h再换3档加速到50 km/h;3)车速由35→10→0 km/h是指:车速由35 km/h换2挡减速到10 km/h并在185 s处脱开离合器减速到0 km/h。

4.2 灰色关联度计算

通过实验得出的数据不可能是线性的,其中由于测试系统的响应等因素的影响不可避免地会有离散点的出现。在这种情况下用灰色理论[9-10]来判断实验数据的关联度是一种简单、科学和实用的方法。由于篇幅的限制,本研究只给出部分数据,根据绝对关联度计算公式计算:

$$\varepsilon_{0i}=\frac{1+|s_0+s_i|}{1+|s_0|+|s_i|+|si-s_0|},$$

$$|s_0|=\left|\sum_{k=2}^{n-1}x_0^0(k)+\frac{1}{2}x_0^0(n)\right|,$$

$$|s_i|=\left|\sum_{k=2}^{n-1}x_i^0(k)+\frac{1}{2}x_i^0(n)\right|,$$

$$|s_i-s_0|=\left|\sum_{k=2}^{n-1}(x_i^0(k)-x_0^0(k))+\frac{1}{2}(x_i^0(n)-x_0^0(n))\right|。$$

4.2.1 计算过程

初始化操作(整理为等长度1的时距序列)。

CO(新):

0.01,0,0,0,0,0,0,0.23,0.4,0.4,0.37,0.36,0.25,0.23,0.21,0.23,0.23,0.33,0.31,0.31,0.28,0.2,0.18,0.17,0.15,0.15,0.11,0.1,0.1,0.1,0.15,0.18,0.2,0.23,0.38,0.43,0.37,0.2,0.11,0.1,0.12,0.27,0.31,0.28,0.25,0.18,0.33,0.43,0.43,0.43,0.3,0.23,0.23,0.25,0.25,0.25,0.17,0.1,0.1,0.21,0.33,0.44,0.52,0.44,0.31,0.23,0.2,0.2,0.2,0.18,0.18,0.18,0.18,0.18,0.18,0.18,0.2,0.2,0.2,0.2,0.2,0.2,0.2,0.2,0.2,0.2,0.2,0.2,0.2,0.2,0.2,0.2,0.2,0.2,0.2,0.2,0.2,0.2,0.2,0.2,0.18,0.05,0.05,0.03,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0.07,0.07,0.07,0.07,0.07,0.15,0.25,0.2,0.11,0.05,0.05,0.03,0,0.02,0.1,0.3,0.38,0.52,0.56,0.52,0.3,0.17,0.1,0.05,0.03,0.05,0.07,0.17,0.18,0.17,0.15,0.15,0.15,0.15,0.15,0.15,0.14,0.11,0.1,0.02,0.01,0.01,0.01,0.02,0.09,0.09,0.07,0.07,0.07,0.07,0.05,0.05,0.05,0.05,0.05,0.05,0.03,0.03,0.03, 0.02,0.02,0.02,0.02,0.02,0.01,0.01,0.01,0.01,0.01,0.01,0.01,0.01,0.01。

CO(中)：

0.41,0.4,0.4,0.4,0.4,0.4,0.4,0.58,0.68,0.69,0.68,0.67,0.56,0.56,0.56,0.54,0.41,0.43,0.46,0.47,0.55,0.55,0.55,0.52,0.52,0.52,0.52,0.52,0.51,0.52,0.72,0.88,1,1,0.98,0.8,0.69,0.68,0.67,0.64,0.63,0.62,0.56,0.47,0.47,0.46,0.46,0.44,0.43,0.43,0.43,0.43,0.43,0.46,0.47,0.5,0.5,0.49,0.47,0.49,0.58,0.75,0.82,0.82,0.79,0.66,0.6,0.58,0.56,0.56,0.56,0.56,0.56,0.56,0.56,0.56,0.55,0.55,0.55,0.55,0.55,0.54,0.54,0.54,0.52,0.52,0.52,0.51,0.51,0.51,0.5,0.5,0.57,0.69,0.79,0.77,0.75,0.72,0.56,0.43,0.34,0.28,0.23,0.18,0.14,0.15,0.15,0.23,0.31,0.33,0.34,0.33,0.23,0.18,0.11,0.09,0.07,0.07,0.07,0.07,0.2,0.43,0.61,0.8,0.91,0.93,0.92,0.89,0.89,0.87,0.67,0.54,0.46,0.41,0.4,0.37,0.37,0.37,0.56,0.66,0.64,0.62,0.47,0.43,0.41,0.4,0.4,0.37,0.37,0.37,0.37,0.36,0.36,0.36,0.36,0.36,0.36,0.36,0.34,0.34,0.34,0.34,0.34,0.34,0.34,0.34,0.34,0.36,0.57,0.67,0.68,0.62,0.49,0.37,0.28,0.25,0.23,0.23,0.23,0.23,0.21,0.21,0.21,0.21,0.21,0.21,0.21,0.23,0.23,0.21,0.21,0.2,0.11,0.11,0.12。

计算绝对关联度(序列的始点零化像)。

CO(新)：

0.00,－0.01,－0.01,－0.01,－0.01,－0.01,－0.01,0.22,0.39,0.39,0.36,0.35,0.24,0.22,0.20,0.22,0.22,0.32,0.30,0.30,0.27,0.19,0.17,0.16,0.14,0.14,0.10,0.09,0.09,0.09,0.14,0.17,0.19,0.22,0.37,0.42,0.36,0.19,0.10,0.09,0.11,0.26,0.30,0.27,0.24,0.17,0.32,0.42,0.42,0.42,0.29,0.22,0.22,0.24,0.24,0.24,0.16,0.09,0.09,0.20,0.32,0.43,0.51,0.43,0.30,0.22,0.19,0.19,0.19,0.17,0.17,0.17,0.17,0.17,0.17,0.17,0.19,0.19,0.19,0.19,0.19,0.19,0.19,0.19,0.19,0.19,0.19,0.19,0.19,0.19,0.19,0.19,0.19,0.19,0.19,0.19,0.19,0.19,0.19,0.19,0.17,0.04,0.04,0.02,－0.01,－0.01,－0.01,－0.01,－0.01,－0.01,－0.01,－0.01,－0.01,－0.01,－0.01,－0.01,－0.01,－0.01,－0.01,－0.01,－0.01,－0.01,0.06,0.06,0.06,0.06,0.06,0.14,0.24,0.19,0.10,0.04,0.04,0.02,－0.01,0.01,0.09,0.29,0.37,0.51,0.55,0.51,0.29,0.16,0.09,0.04,0.02,0.04,0.06,0.16,0.17,0.16,0.14,0.14,0.14,0.14,0.14,0.14,0.13,0.10,0.09,0.01,0.00,0.00,0.00,0.01,0.08,0.08,0.06,0.06,0.06,0.06,0.04,0.04,0.04,0.04,0.04,0.04,0.02,0.02,0.02,0.01,0.01,0.01,0.01,0.01,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00,0.00。

CO(中)：

0.00,－0.01,－0.01,－0.01,－0.01,－0.01,－0.01,0.17,0.27,0.28,0.27,0.26,0.15,0.15,0.15,0.13,0.00,0.02,0.05,0.06,0.14,0.14,0.14,0.11,0.11,0.11,0.11,0.11,0.10,0.11,0.31,0.47,0.59,0.59,0.57,0.39,0.28,0.27,0.26,0.23,0.22,0.21,0.15,0.06,0.06,0.05,0.05,0.03,0.02,0.02,0.02,0.02,0.02,0.05,0.06,0.09,0.09,0.08,0.06,0.08,0.17,0.34,0.41,0.41,0.38,0.25,0.19,0.17,0.15,0.15,0.15,0.15,0.15,0.15,0.15,0.15,0.14,0.14,0.14,0.14,0.14,0.13,0.13,0.13,0.11,0.11,0.11,0.10,0.10,0.10,0.09,0.09,0.16,0.28,0.38,0.36,0.34,0.31,0.15,0.02,－0.07,－0.13,－0.18,－0.23,－0.27,－0.26,－0.26,－0.18,－0.10,－0.08,－0.07,－0.08,－0.18,－0.23,－0.30,－0.32,－0.34,－0.34,－0.34,－0.34,－0.21,0.02,0.20,0.39,0.50,0.52,0.51,0.48,0.48,0.46,0.26,0.13,0.05,0.00,－0.01,－0.04,－0.04,－0.04,0.15,0.25,0.23,0.21,0.06,0.02,0.00,－0.01,－0.01,－0.04,－0.04,－0.04,－0.04,－0.05,－0.05,－0.05,－0.05,－0.05,－0.05,－0.05,－0.07,－0.07,－0.07,－0.07,－0.07,－0.07,－0.07,－0.07,－0.07,－0.05,0.16,0.26,0.27,0.21,0.08,－0.04,－0.13,－0.16,－0.18,－0.18,－0.18,－0.18,－0.20,－0.20,－0.20,－0.20,－0.20,－0.20,－0.20,－0.18,－0.18,－0.20,－0.20,－0.21,－0.30,－0.30,－0.29。

计算 $|S_0|$，$|S_1|$，$|S_1-S_0|$ 及绝对关联度。

$|S_0|=27.41$，$|S_1|=11.785$，$|S_1-S_0|=15.625$，绝对关联度＝0.720 1。

用同样的方法和步骤可以计算出其他参数序列之间的绝对关联度。

4.2.2 计算结果

CO(新)和CO(中)的绝对关联度为0.72，CO(新)和CO(旧)的绝对关联度为0.67，HC(新)和HC(中)的绝对关联度为0.99，HC(新)和HC(旧)的绝对关联度为0.93。

从计算结果中可以看出，以新轮胎作为行为序列时，更换中、旧轮胎后根据所得实验数据计算得出的与行为序列绝对关联度，无论是CO还是HC与行为序列的绝对关联度，磨损严重的均小于磨损中等程度的，也就是说，用磨损程度中等的轮胎测得的试验数据与几乎没有磨损的新轮胎测得的试验数据比较，其结果比换用磨损严重的旧轮胎更接近。这说明磨损严重的轮胎对汽车排放特性的影响更大。这一结果与**4.1**的分析计算结果一致。

5 结 语

本研究通过实验得出的数据考察了轮胎磨损程度对汽车排放特性的影响，结果显示，轮胎的磨损程度对其排放特性有直接的影响，特别是在加速段和减速工况时影响尤为明显。用灰色系统理论分析的关联度也表明轮胎磨损程度对在用车的排放特性有直接的影响。该实验研究为控制在用车的排放提供了理论和实践依据。

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