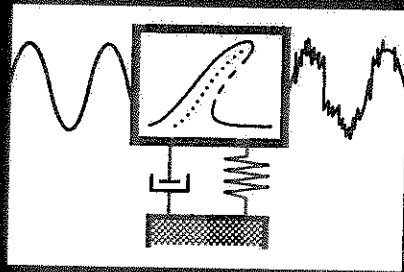


September 2013, Volume 15, Issue 3
Pages (1081-1626), NoP (1024-1073)
ISSN 1392-8716

JVE Journal of Vibroengineering



JVE Journal of Vibroengineering

SEPTEMBER 2013. VOLUME 15, ISSUE 3, PAGES (1081-1626). NUMBERS OF PUBLICATIONS FROM 1024 TO 1073, ISSN 1392-8716

Contents

1024. FINDING CHEBYSHEV SERIES PERIODIC SOLUTIONS OF NONLINEAR VIBRATION SYSTEMS VIA OPTIMIZATION METHOD 1081
WEI ZHOU, JINGLONG HAN, QUANLONG CHEN
1025. COMBUSTION TIMING VARIABILITY IN A LIGHT BOOSTED CONTROLLED AUTO-IGNITION ENGINE WITH DIRECT FUEL INJECTION 1093
JACEK HUNICZ, MICHAL GECA, ANDRZEJ RYSAK, GRZEGORZ LITAK, PAWEŁ KORDOS
1026. MATHEMATICAL MODELING OF STEPPING MOTOR AND VIBRATION TORQUE MECHANISM RESEARCH ON ITS DIFFERENT OPERATIONS 1102
HAO ZHAO, HAO FENG
1027. IMPACT OF WHOLE BODY VIBRATION ON BALANCE IMPROVEMENT IN ELDERLY WOMEN 1112
VILMA DUDONIENE, RASA SAKALIENE, LIGIJA SVEDIENE, DAINA KAZLAUSKIENE, JAN SZCZEGIELNIAK, GRAZINA KRUTULYTE
1028. A THERMODYNAMICS COUPLED MODELING APPROACH FOR ANALYSIS AND IMPROVEMENT OF HIGH-SPEED MOTORIZED SPINDLE SYSTEM 1119
ZHOUPI WU, BEIZHI LI, JIANGUO YANG, XIA SHENG
1029. ESTIMATION OF SHELL RADIATION EFFICIENCY USING A FEM-SMEDA ALGORITHM 1130
QIAO Y., CHEN H. B., LUO J. L.
1030. FAULT DIAGNOSIS METHOD USING SUPPORT VECTOR MACHINE WITH IMPROVED COMPLEX SYSTEM GENETIC ALGORITHM 1147
QINGYU YANG, DI ZHANG, JIAN ZHUANG, FENGWEI SUN, JING WANG
1031. NOISE REDUCTION FOR ULTRASONIC LAMB WAVE SIGNALS BY EMPIRICAL MODE DECOMPOSITION AND WAVELET TRANSFORM 1157
XIAO CHEN, JING LI
1032. A NEW TRANSIENT FIELD BALANCING METHOD OF A ROTOR SYSTEM BASED ON EMPIRICAL MODE DECOMPOSITION 1166
GUANGRUI WEN, TINGPENG ZANG, YUHE LIAO, LIN LIANG
1033. EFFECTS OF GUIDE VANE THICKNESS ON PRESSURE PULSATION OF MIXED-FLOW PUMP IN PUMPED-STORAGE POWER STATION 1177
WEI LI, WEIDONG SHI, YANDONG XU, LING ZHOU, PINGPING ZOU

CONTENTS

	1034. A SAMPLE-DRIVEN CLASSIFICATION AND IDENTIFICATION METHOD WITH KPCA AND MULTI-SVM	1186
	XIANGYANG JIN, ZHIHUI SUN, XIANGYI GUAN, TIEFENG ZHANG, MING PANG, HANLIN YANG	
	1035. THE INFLUENCE OF VISCOUS LIQUID TO THE PROPAGATION OF TORSIONAL WAVE IN PIPES	1194
	YONGMING FENG, YONG YAN, JIANYUAN YANG, WEIDONG CHEN	
	1036. THERMAL-HYDRAULIC MODELLING AND ANALYSIS OF HYDRAULIC DAMPER FOR IMPACT CYLINDER WITH LARGE FLOW	1208
	Y. GUO, C. P. LIU, B. W. LUO	
	1037. DECOUPLING THE ALIASED SPECTRA OF ROLLING BEARING WITH MULTISPEED MULTIPLE FREQUENCY CORRELATION	1221
	ZHONGQIU WANG, ZHENCAI ZHU, WEI LI	
	1038. ADAPTIVE INPUT ESTIMATION METHOD AND FUZZY ROBUST CONTROLLER COMBINED FOR ACTIVE CANTILEVER BEAM STRUCTURAL SYSTEM VIBRATION CONTROL	1230
	MING-HUI LEE	
	1039. EXTENSION OF PIECEWISE EXACT SOLUTION METHOD FOR TWO- AND THREE-DIMENSIONAL FLUID FLOWS	1243
	HYOSEOB KIM, JONGSUP AHN, CHANGHWAN JANG, JAEYOULL JIN, BYUNGSOON JUNG	
1081	1040. RESEARCH ON TOUCHDOWN PERFORMANCE OF SOFT-LANDING SYSTEM WITH FLEXIBLE BODY	1255
	JINBAO CHEN, HONG NIE, WEI BO	
1093	1041. PARAMETER OPTIMIZATION AND ACTIVE VIBRATION SUPPRESSION CONTROL IN GYROSCOPIC SYSTEM	1263
	ZHIHUAN ZHANG, SULTAN A. Q. SIDDIQUI, CHAO HU	
1102	1042. STUDY OF VIBRATION CHARACTERISTICS OF THE SHORT THIN CYLINDRICAL SHELLS AND ITS EXPERIMENT	1270
	ZHONG LUO, NING SUN, YU WANG, KAI ZHANG, QINGKAI HAN	
1112	1043. DESIGN AND TEST ON ULTRASONIC COMPOUND SYNCHRONIZING MICRO-FINE ELECTRICAL MACHINING SYSTEM	1284
	ZHU YONGWEI, SU NAN, ZHEN DONGZHI	
1119	1044. EFFECTS OF THE DYNAMIC VEHICLE-ROAD INTERACTION ON THE PAVEMENT VIBRATION DUE TO ROAD TRAFFIC	1291
	ZHENG LU, HAILIN YAO	
1130	1045. VIBRATION OF FLEXIBLE ROTOR SYSTEMS WITH TWO-DEGREE-OF-FREEDOM PID CONTROLLER OF ACTIVE MAGNETIC BEARINGS	1302
	Z. X. ZHONG, C. S. ZHU	
1147	1046. BLADES RUBS AND LOOSENESS DETECTION IN GAS TURBINES – OPERATIONAL FIELD EXPERIENCE AND LABORATORY STUDY	1311
	LEONG M. S., LIM MENG HEE	
1157	1047. REDESIGNING COMPONENTS OF POWER TRANSMISSION ACCORDING TO NUMERICAL MODEL AND VIBRATION DIAGNOSTICS	1322
	PREDRAG JOVANČIĆ, ŠEFKET ČELOVIĆ, DRAGAN IGNJATOVIĆ, TAŠKO MANESKI	
1166	1048. PRECISE FINITE ELEMENT MODELING AND ANALYSIS OF DYNAMICS OF LINEAR ROLLING GUIDEWAY ON SUPPORTING DIRECTION	1330
	WEI SUN, XIANGXI KONG, BO WANG	
1177	1049. CHARACTERIZATION OF THE DYNAMIC INTERACTION BETWEEN CHASSIS AND POWERTRAIN OF A VEHICLE USING THE COUPLING MATRIX	1341
	ALI EL HAFIDI, ALEXANDRE LOREDO, BRUNO MARTIN	

1050. PASSIVE REDUCTION OF SYSTEM VIBRATIONS TO THE DESIRED AMPLITUDE VALUE ANDRZEJ DYMAREK, TOMASZ DZITKOWSKI	1354	106
1051. DETAILED ANALYSIS OF DRUM BRAKE SQUEAL USING COMPLEX EIGENVALUE ANALYSIS PEVEC MIHA, ODER GREGA, POTRČ IZTOK, ŠRAML MATJAŽ	1365	106
1052. ENSEMBLE LEARNING-BASED INTELLIGENT FAULT DIAGNOSIS METHOD USING FEATURE PARTITIONING YONGSHENG ZHU, XIAORAN ZHU, JING WANG	1378	107
1053. IDENTIFICATION OF JOINT PARAMETERS USING FRF BASED DECOUPLING HEE-CHANG EUN, EUN-TAIK LEE, JAE-OH KOO	1393	107
1054. A HYBRID OBJECTIVE FUNCTION FOR DAMAGE IDENTIFICATION VIA IMPERIALISTIC COMPETITIVE ALGORITHM (ICA) MEHDI MASOUMI, EHSAN JAMSHIDI, MAHDI BAMDAD	1402	107
1055. OPTIMAL TIME DELAY CONTROL FOR NONLINEAR VIBRATION OF SINGLE WALLED CARBON NANO-TUBE ON ELASTIC MEDIUM CANCHANG LIU, CHUANBO REN, LU LIU, LIJUN LI	1409	107
1056. A FAST ALGORITHM FOR CALCULATION OF RANDOM RESPONSE OF ELASTIC THIN PLATE UNDER DISTRIBUTED RANDOM LOAD JIANG JINHUI, CHEN GUOPING, ZHANG FANG	1419	
1057. POWER TILLER VIBRATION ACCELERATION ENVELOPE CURVES ON TRANSPORTATION MODE HOSSEIN AHMADIAN, SEYED REZA HASSAN-BEYGI, BARAT GHOBADIAN	1431	
1058. COUPLING VIBRATION ANALYSIS OF AUGER DRILLING SYSTEM SONGYONG LIU, XINXIA CUI, XIAOHUI LIU	1442	
1059. STUDY ON THE VIBRATION EFFECT ON OPERATION SUBWAY INDUCED BY BLASTING OF AN ADJACENT CROSS TUNNEL AND THE REDUCING VIBRATION TECHNIQUES XINGHUA LI, YUAN LONG, CHONG JI, MINGSHOU ZHONG, HUABING ZHAO	1454	
1060. LAMB WAVE TEMPERATURE COMPENSATION METHOD BASED ON ADAPTIVE FILTER ADALINE NETWORK LEI QIU, SHENFANG YUAN, TIANXIANG HUANG	1463	
1061. NUMERICAL RESEARCH ON RUB-IMPACT FAULT IN A BLADE-ROTOR-CASING COUPLING SYSTEM HUI MA, XINGYU TAI, HEQIANG NIU, RONGZE SONG	1477	
1062. A SPRING DASHPOT MODEL FOR DYNAMIC ANALYSIS OF BEAM-LIKE STRUCTURE WITH CLEARANCE BING LI, WEI JIN, LUOFENG HAN, HONGRUI CAO, ZHENGJIA HE	1490	
1063. SEISMIC PERFORMANCE OF A ROLLING-DAMPER ISOLATION SYSTEM BIAO WEI, RUIBO CUI, GONGLIAN DAI	1504	
1064. CONVERSION AND ITS DEVIATION CONTROL OF ELECTRIC SWITCH MACHINE OF HIGH SPEED RAILWAY TURNOUT RONG CHEN, PING WANG, HAO XU	1513	
1065. IDENTIFICATION OF PIECEWISE LINEAR AEROELASTIC SYSTEMS ZHITAO LI, JINGLONG HAN, HAIWEI YUN	1526	
1066. A SELF-ADAPTIVE ALARM METHOD FOR TOOL CONDITION MONITORING BASED ON PARZEN WINDOW ESTIMATION XIAOGUANG CHEN, GUANGHUA XU	1537	
1067. PERFORMANCE ASSESSMENT OF HYDRAULIC SERVO SYSTEM BASED ON BI-STEP NEURAL NETWORK AND AUTOREGRESSIVE MODEL CHEN LU, HANG YUAN, LAIFA TAO, HONGMEI LIU	1546	

CONTENTS

1354	1068. THE DIAGNOSIS OF ROLLING BEARING BASED ON THE PARAMETERS OF PULSE ATOMS AND DEGREE OF CYCLOSTATIONARITY XINQING WANG, HUIJIE ZHU, DONG WANG, YANG ZHAO, YANFENG LI	1560
1365	1069. NONLINEAR BEHAVIOR ANALYSIS OF Z-SOURCE DC/DC CONVERTER BASED ON CURRENT CONTROL CHEN YAN, ZHENG YONG	1576
1378	1070. THE VIBROSTABILIZATION OPTIMIZATION OF A SORTING ARM STRUCTURE TAO LIU, BIN LI, SHUTING WANG, KUANMIN MAO	1585
1393	1071. DYNAMIC STABILITY ANALYSIS ON LARGE WIND TURBINE BLADE UNDER COMPLICATED OFFSHORE WIND CONDITIONS J. P. ZHANG, D. L. LI, Y. HAN, D. M. HU, J. X. REN	1597
1402	1072. INFORMATION EXERGY-BASED METHOD FOR STRUCTURAL DAMAGE DIAGNOSIS BIN ZHANG, LIJUN ZHANG, JINWU XU, JIAN LIU	1606
1409	1073. DYNAMICS STUDY OF THE CARRIER HMMWV M1151 A. FEDARAVIČIUS, V. JONEVIČIUS, A. SURVILA, A. PINCEVIČIUS	1619
1419		
1431		
1442		
1454		
1463		
1477		
1490		
1504		
1513		
1526		
1537		
1546		

1073. Dynamics study of the carrier HMMWV M1151

A. Fedaravičius¹, V. Jonevičius², A. Survila³, A. Pincevičius⁴

^{1,3}Kaunas University of Technology, Institute of Defence Technologies
Kęstučio Str. 27, 44312 Kaunas, Lithuania

²Vilnius Gediminas Technical University, Plytinės Str. 27, LT-10105 Vilnius, Lithuania

⁴Military Academy of Lithuania, Šilo Str. 5a, LT-10322 Vilnius, Lithuania

E-mail: ¹algimantas.fedaravicius@ktu.lt, ²vaclovas.jonevicius@ti.vgtu.lt, ³arvydas.survila@ktu.lt, ⁴pincev@cablenet.lt

(Received 9 July 2013; accepted 4 September 2013)

Abstract. The article deals with the influence of the shot recoil of various weapons mounted on the armored vehicle HMMWV M1151 influencing the vehicle vibration when driving on uneven road surfaces. The solutions are given to ensure the safety of the crew when installing the non-standard weapon systems on the off-road vehicles.

Keywords: armored vehicle, gun shot, recoil, mass center oscillations.

1. Introduction

Tactical armoured vehicles are characteristic of a good protection of a crew and transportation of troops against small arms bullets and small calibre projectile fragments. They are widely used in contemporary military conflicts and international peacekeeping operations. Therefore a great attention is paid for their development and improvement in armed forces of NATO countries [1].

A modern vehicle consists of a number of mechanisms and systems the functioning of which is interrelated. The principles of vehicle design and theoretical background of their operation are presented in the publications of T. K. Garrett, H. Heisler, J. Y. Wong and other researchers [2, 3, 4]. Modern vehicles and particularly military often are operated in difficult off-road conditions where dynamical parameters of suspension, wheels, road and other systems are of crucial importance for achieving the necessary performance parameters what is presented in the publications of R. N. Jazar, H. B. Pacejka, K. Popp, W. Schihlen and other researchers [5, 6, 7, 8]. Great influence on dynamical properties and stability of a military vehicle has the armament installed in it as during shots it plays the role of powerful excitation source [9, 10].

At the moment of firing, the gun shot creates vibrations that are transmitted to the combat vehicle corps. The carrier corps oscillation has a large influence on the security of the carrier movement; high amplitude of oscillation increases the drivers and crew fatigue, driving becomes dangerous. When firing with armoured mounted machine gun additional vibrations appear and having assessed the influence of these vibrations it would be possible to assess the driving safety with the machine gun firing in different directions and to make assumptions whether more powerful weapons can be mounted on the armoured vehicle.

The Lithuanian army use a number of HMMWV M1151 vehicles with mounted 12.7 heavy machine guns. The article will investigate the influence of armoured gun recoil on the dynamics of vertical vibrations of the armoured vehicle and possibilities to install on the HMMWV M1151 heavier weapons such as 14.5 mm heavy machine gun and the 20 mm cannon.

When firing from the 12.7 mm HMMWV M1151 heavy machine gun mounted on a vehicle, additional forces appear which also influence the vehicle chassis. This effect increases when driving on a rough road surfaces. Since the Lithuanian army plans to use these tactical armoured vehicles for a long period in future, it is important to have a possibility to mount more powerful weapons on these vehicles. When the maximum vertical displacements of the chassis are identified, conclusions can be drawn on the meaning fullness of modernization and its costs.

2. Recoil effect on the shooter

Recoil – weapon’s movement backwards at the moment of firing. A shot causes the sound, a

itoring.
17-19,
fication
-106.
Journal
analysis
bration
-71, (in
nlinear
/of. 16,
Journal
ctivity
87.

ode

ode

ode

weapon moves backwards and the shooter experiences a shock. Thus, recoil is a mechanical and psychological effect on the shooter. Recoil shock value largely depends on the shooter's physical parameters that are determined by the skeletal and muscular structure, and the handling conditions of a weapon [9]. When the weapon is mounted on a heavy armoured vehicle, recoil size largely depends on the fortification design and vehicle weight.

If a weapon and a bullet weights are the same, then, a weapon during the firing moves at the same speed as a bullet, but in the opposite direction. We can state that the heavier is a weapon, the smaller is the recoil and vice versa, the heavier is a bullet and the stronger is the powder power that gives higher initial velocity to the bullet, the stronger will be the recoil.

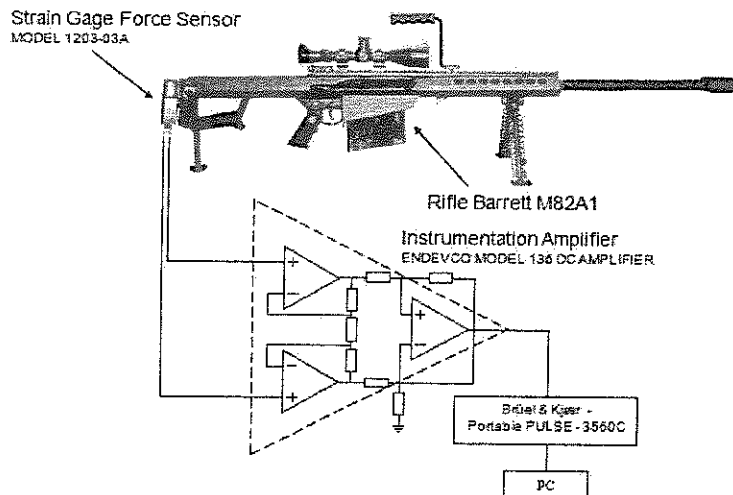


Fig. 1. "Barrett" with a recoil measurement connected equipment

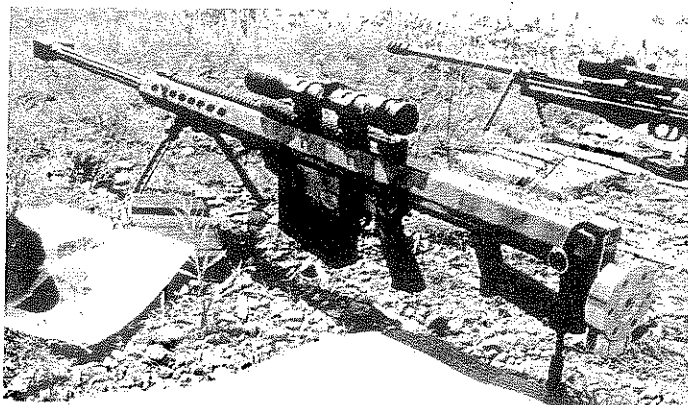


Fig. 2. "Barrett" in the butts with the scheme

When a weapon is mounted on the armoured tactical vehicle, the vehicle weight is as if added to the weapon's mass and a heavier weapon effect are observed. Higher weight resists the recoil therefore the recoil will be smaller. To the contrary, if there was no resisting mass, the recoil would be much greater.

Therefore, when the recoil is measured or calculated, the term "free recoil" should be defined, which a recoil velocity or energy caused by a weapon to which no additional weight is added, i.e. the influence of vehicle mass on the movement of a weapon is ignored. A weapon is as if hanging in the air and a shot is made. "Barrett" rifle recoil measurements were made when firing with 12.7 mm bullets.

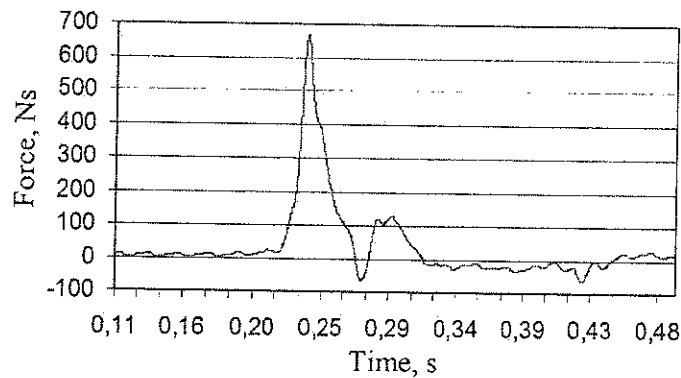


Fig. 3. "Barrett" recoil measurement results

Instrumentation amplifier equipment was used to measure the recoil (Fig. 1, 2). The equipment was connected to the strain gage force sensor. Signal was stored by Brüel & Kjær portable Pulse 3600C software and displayed on a portable computer screen.

We see that the recoil reaches the peak value of 980 N and the force impulse is 15.07 Ns approximately, what does not cause any particular problems to the shooter (Fig. 3).

3. Recoil components and principles of its parameters' identification

Weapon recoil is caused by three factors [9]:

- reaction accompanied by the bullet acceleration from the still position till the moment the bullet leaves the weapon at the so called muzzle velocity at a weapon muzzle;
- reaction accompanied by gunpowder charge acceleration up to a half of the muzzle velocity.

When a bullet leaves a weapon, gunpowder gas fills the entire barrel and cartridge slot. Part of the gas moves together with a bullet at the same speed, the other part of the gas remains in the cartridge slot. Therefore, gunpowder gas average city in the barrel is calculated by dividing the speed of a bullet by two.

- reaction accompanied by the explosion of gunpowder gas going out of the weapon barrel when the bullet leaves the weapon and releases the gas, which thus causes a "rocket" effect.

The main recoil calculation principles are based on the principles of Newton's third and momentum conservation laws.

Having assessed the bullet movement in the barrel acceleration and the length of the gun barrel, it is possible to calculate the gas-generated gunpowder force F_a :

$$F_a = \frac{m_K v_K^2}{2s_V}, \quad (1)$$

here m_K – mass of the bullet; v_K – muzzle velocity at a weapon muzzle; s_V – the gun barrel length. The expressions of this section are used to determine the absolute magnitudes of the recoil.

The recoil is composed of two parts: primary and secondary recoil. The primary recoil is caused by the force acting on a weapon. The same size only the opposite direction force is acting on a bullet. Based on the dynamics of linear momentum theorem:

$$m_K v_K - m_G v_G = 0, \quad (2)$$

m_G – mass of the weapon, v_G – velocity of the weapon recoil velocity.

When $v_K = 853$ m/s, $m_K = 0.0428$ kg, $m_G = 14$ kg ("Barrett" sniper rifle 12.7x99 mm is used):

$$v_G = -\frac{m_K v_K}{m_G} = -\frac{0.0428 \cdot 853}{14} = -2.6 \text{ m/s.} \quad (3)$$

The bullets kinetic energy is calculated as follows:

$$KKE = \frac{1}{2} m_K v_K^2 = \frac{1}{2} 0.0428 \cdot 853^2 = 15570 \text{ J.} \quad (4)$$

The recoil force influencing the weapon:

$$F = \frac{KKE}{s} = \frac{15570}{0.736} = 21154.9 \text{ N,} \quad (5)$$

where s – the barrel length ($s = 0.736 \text{ m}$).

The secondary recoil is reduced to the minimum having made the cuts at the barrel end. Outgoing gas is dissipated and it does not significantly influence the movement of a weapon at the moment of firing. Therefore, we will further analyze the weapon recoil, paying no attention to the effect of the gas.

We see that the theoretically calculated recoil significantly differs from the recoil measured with the device support. This shows the efficiency of the gas compensator, which creates good conditions for the shooter. We make a scheme of forces acting on HMMWV M1151 vehicle moving at the speed of 15 m/s and firing at the maximum rate of 2 seconds. We write down the differential equations of a weapon planar motion.

4. Development of the mathematical model and research of the planar motion of a vehicle with a weapon

4.1. Dynamic model of the HMMWV vehicle

Planar motion of a vehicle with a weapon at the moment of firing is analyzed considering the spring and damping characteristics of a vehicle. For that purpose dynamic and mathematical models of a vehicle at the moment of firing in planar were made. We consider a vehicle with a weapon as an entire body mass as the weapon is mounted on the heavy armoured vehicle.

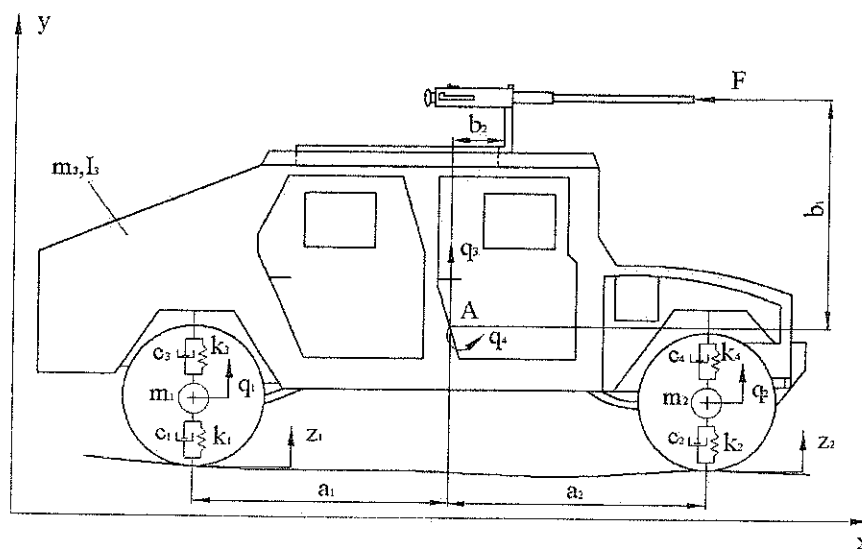


Fig. 4. Dynamic model of the M1151 HMMWV vehicle

(3) Planar movement of the vehicle is analysed. The gravity centre of the vehicle is point A. The weapon and vehicle interaction in the model is simulated by the mechanical springs with rigid elements k_1, k_2, k_3, k_4 and dampers with viscous elements c_1, c_2, c_3, c_4 . Force F initiating the weapon recoil was calculated in section 3. We write down the system's kinetic energy [12]:

(4)
$$T = \frac{1}{2} m_1 \cdot \dot{q}_1^2 + \frac{1}{2} m_2 \cdot \dot{q}_2^2 + \frac{1}{2} m_3 \cdot \dot{q}_3^2 + \frac{1}{2} I_3 \cdot \dot{q}_4^2. \quad (6)$$

Potential energy of the system:

(5)
$$\Pi = \frac{1}{2} k_1 (q_1 - z_1)^2 + \frac{1}{2} k_2 (q_2 - z_2)^2 + \frac{1}{2} k_3 (q_3 - a_1 q_4 - q_1)^2 + \frac{1}{2} k_4 (q_3 + a_2 q_4 - q_2)^2. \quad (7)$$

Suppressive function of the system:

(8)
$$\Phi = \frac{1}{2} k_1 (\dot{q}_1 - \dot{z}_1)^2 + \frac{1}{2} k_2 (\dot{q}_2 - \dot{z}_2)^2 + \frac{1}{2} k_3 (\dot{q}_3 - a_1 \dot{q}_4 - \dot{q}_1)^2 + \frac{1}{2} k_4 (\dot{q}_3 + a_2 \dot{q}_4 - \dot{q}_2)^2. \quad (8)$$

We use second degree equation of Lagrange:

(9)
$$\frac{d}{dt} \left(\frac{\partial T}{\partial \dot{q}_i} \right) - \frac{\partial T}{\partial q_i} + \frac{\partial \Pi}{\partial q_i} + \frac{\partial \Phi}{\partial \dot{q}_i} = Q_i.$$

We write down the differential equations of the planar motion of the vehicle:

(10)
$$\begin{aligned} m_1 \ddot{q}_1 + k_1 (q_1 - z_1) + c_1 (\dot{q}_1 - \dot{z}_1) - k_3 (q_3 - a_1 q_4 - q_1) - c_3 (\dot{q}_3 - a_1 \dot{q}_4 - \dot{q}_1) &= -m_1 g, \\ m_2 \ddot{q}_2 + k_2 (q_2 - z_2) + c_2 (\dot{q}_2 - \dot{z}_2) - k_4 (q_3 - a_2 q_4 - q_2) - c_4 (\dot{q}_3 - a_2 \dot{q}_4 - \dot{q}_2) &= -m_2 g, \\ m_3 \ddot{q}_3 + k_3 (q_3 - a_1 q_4 - q_1) + k_4 (q_3 + a_2 q_4 - q_2) + c_3 (\dot{q}_3 - a_1 \dot{q}_4 - \dot{q}_1) & \\ + c_4 (\dot{q}_3 + a_2 \dot{q}_4 - \dot{q}_2) &= -m_2 g, \\ I_3 \ddot{q}_4 - a_1 k_3 (q_3 - a_1 q_4 - q_1) + a_2 k_4 (q_3 + a_2 q_4 - q_2) + a_1 c_3 (\dot{q}_3 - a_1 \dot{q}_4 - \dot{q}_1) & \\ + a_2 c_4 (\dot{q}_3 + a_2 \dot{q}_4 - \dot{q}_2) &= F \cdot b_1. \end{aligned} \quad (10)$$

The force acting on the car is described according to the variable function:

(11)
$$F(t) = F \cdot \sin(\omega \cdot t),$$

where F is the force acting on the car during the firing, ω – angular frequency, t – time. This function shows that the recoil force of the firing with a machine gun mounted on the armoured vehicle is 600 rounds per minute.

Differential equations of the planar motion of the vehicle with the weapon were solved with the Maple mathematical package using the Runge-Kutta method. We assume that the initial displacements, velocities and accelerations are equal to 0. Data values used in differential equations and the main weapons parameters are given in Table 1 [13].

Table 1. Weapons parameters

Round, mm	Bullet weight, kg	Muzzle velocity	Muzzle energy, J	Length of the barrel, m	Rate of fire, rds/min
12.7x99	0.0429	887	16876	1.14	600
14.5x114	0.06344	976	30215	1.346	600
30x113	0.237	800	81000	1.55	720

4.2. Vehicle dynamics using 12.7 mm machine gun Browning 50

The calculation process and formatting of the results are carried out with Maple mathematical package.

When shooting with the machine gun Browning at the maximum speed, every shot occurs approximately every 0.1 s.

Displacements of the key elements of the vehicle chassis are illustrated in Fig. 5.

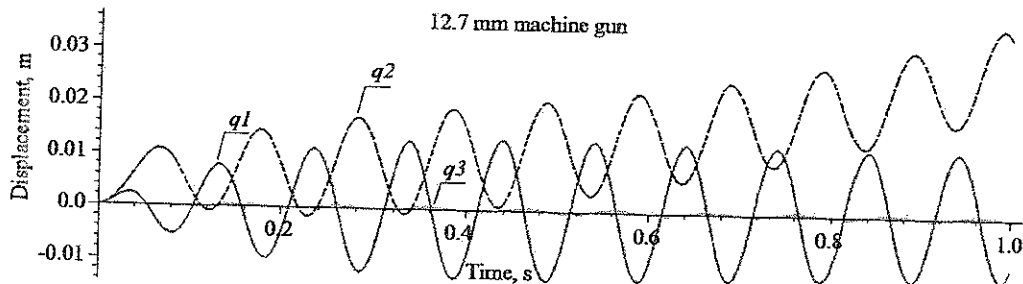


Fig. 5. Displacements of the main chassis components of the vehicle HMMWV M1151 when firing with a 12.7 mm heavy machine gun Browning 50

The obtained result shows that the recoil force influences the vehicle at its maximum force in a sinusoidal curve every 0.1 s, and the most dangerous situation for the vehicle occurs when driving on rough road and firing in the direction of movement as shown in Fig. 5, 6.

We see that the displacement of the centre of the vehicle at the moment of firing with a weapon of 12.7 mm calibre is about 0.02 m and its amplitude does not increase.

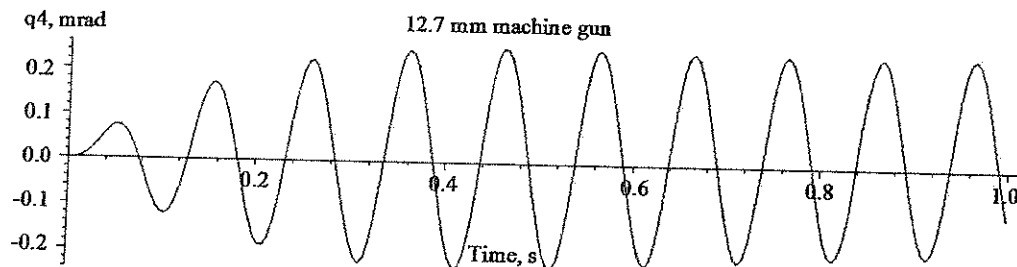


Fig. 6. Oscillations of the mass centre of the carrier HMMWV M1151 when firing with the heavy machine gun Browning 50

The carrier center variations in the picture are stable. We may conclude that the vehicle swinging when driving with the existing chassis over a rough road at the speed of 15 m/s and firing at the maximum rate of fire in the direction of movement can be considered not dangerous.

4.3. Vehicle dynamics using more powerful 14.5x114 mm and 30x113 mm weapon systems

Using the same parameters and the chassis of the vehicle and travelling at the same speed and on the same road, but firing with a large calibre machine gun, such as using KPVT using 14.5x108 mm ammunition, we get the chart of the displacement of the main chassis components.

Fig. 7 shows that after 4th shot the displacement of the chassis element q_2 sharply increases and firing in the direction of movement is complicated. It shows that the vehicle swinging after the fourth to fifth shot the system does not set back in place, which suggests the need for armoured vehicle to stop or stop firing.

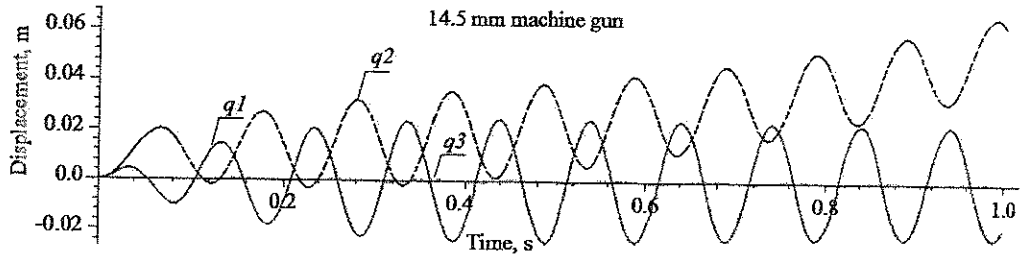


Fig. 7. Displacements of the main chassis components of the vehicle HMMWV M1151 when firing with a machine gun KPVT

Having mounted on the current carrier's chassis cannon firing 30x113 ammunition, we calculate displacement of the carrier's chassis key elements depending on the time shift under the same conditions but the shooting rate is 720 shots per minute.

When shooting with bullets 14.5x114, displacement q_2 becomes higher than 0.04 m after sixth shots, however, when shooting with a 30 mm cannon ammunition 30x113, after two shots (Fig. 7, 9).

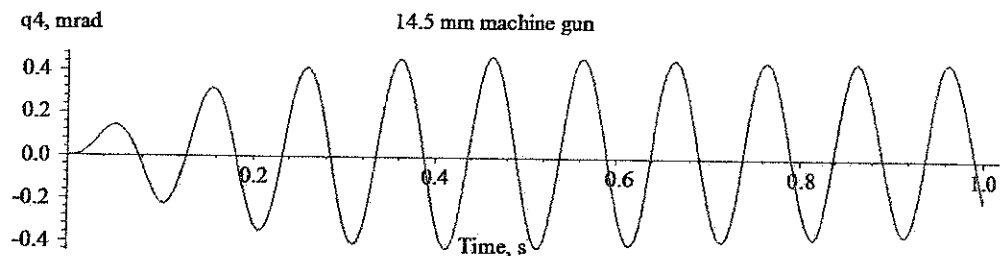


Fig. 8. Oscillations of the mass centre of the carrier HMMWV M1151 when firing with the heavy machine gun KPVT

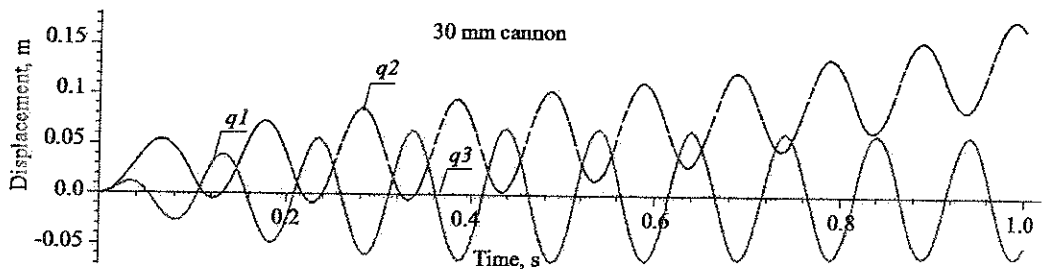


Fig. 9. Displacements of the main chassis components of carrier HMMWV M1151 when shooting with 30 mm cannon

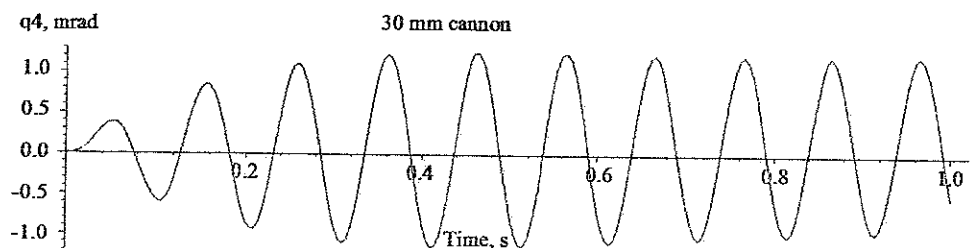


Fig. 10. Oscillations of the mass centre of the carrier HMMWV M1151 when firing with the 30 mm cannon

In the Fig. 10 the oscillations of the mass centre of the carrier HMMWV M1151 are presented. From the data presented in Figs. 6, 8, 10 it can be observed that amplitudes of angular oscillations of the vehicle chassis grow from 0.2 to 1 mrad in case of weapon's calibre increase and correspond the tendencies of displacement change of other chassis elements.

5. Conclusions

Having performed the theoretical calculations and assessed the obtained results, we can judge that shooting while driving on an uneven road surface with standard 12.7x99 mm calibre cartridges has no significant effect on armoured tactical vehicle HMMWV M1151.

In order to be able to use the chassis of the off-road tactical carrier HMMWV M1151 in more powerful weapon systems, vehicle chassis – weapon systems modification is necessary.

In case of military emergency, having installed on the tactical carrier HMMWV M1151 chassis more powerful weapon systems it is absolutely necessary to strictly avoid shooting longer than 3 to 4 shots volleys.

References

- [1] Priegnitz J. Future armoured and non-armoured vehicles in the German army. *Military Technology*, Vol. 23, Issue 2, 1999, p. 43-49.
- [2] Garrett T. K., Newton K., Steeds W. *The Motor Vehicle*. 13th ed., Oxford, Elsevier Butterworth-Heinemann, 2001, p. 1188.
- [3] Heister H. *Advanced Vehicle Technology*. 2nd ed., Oxford, Elsevier Butterworth-Heinemann, 2005, p. 664.
- [4] Wong J. Y. *Theory of Ground Vehicles*. John Wiley & Sons, Inc., Hoboken, New Jersey, 2008, p. 560.
- [5] Jazar R. N. *Vehicle Dynamics: Theory and Application*. Springer, 2008, p. 1015.
- [6] Pacejka Hans B. *Tyre and Vehicle Dynamics (Second Edition)*. Published by Elsevier Ltd., Oxford, UK, 2006, p. 238-256.
- [7] Popp K., Schihlen W. *Ground Vehicles Dynamics*. Springer, 2010, p. 350.
- [8] Sapragonas J., Makaras R. Investigation of movement of the off-road vehicles under roadless conditions. *Journal of Vibroengineering*, Vol. 13, Issue 3, 2011, p. 334-341.
- [9] Szmit L., Wozniak R. Specificity of design and action of the weapon's jump and recoil laboratory test stand. *Problems of Mechatronics (Armament, Aviation, Safety Engineering)*, Vol. 3, Issue 9, 2012, p. 29-39.
- [10] Droppa P., Stiavnicky M. Vibrations simulation of wheeld vehicles. *Problems of Mechatronics (Armament, Aviation, Safety Engineering)*, Vol. 2, Issue 8, 2012, p. 17-28.
- [11] Lyman R. *48th Edition Reloading Handbook*. Lyman Publishing Corporation – Connecticut, 2003, p. 480.
- [12] Bela L. Sandor *Engineering Mechanics Statics and Dynamics*. 2nd ed., Prentice Hall, Inc., Englewood Cliffs, N. J., 1987, p. 928.
- [13] Dapkevičius G. *The Reference Book of the Foreign Countries Land Force*. Military Academy of Lithuania, 1996, p. 197-216.