MATEC Web of Conferences **334**, 02006 (2021) https://doi.org/10.1051/matecconf/202133402006
ITMTS 2020

Ways of Solving of Safety Problems of Single-Track Vehicles

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Abstract. This article describes the ways of solving essential problems regarding the safety of single-track vehicles (STV). All test procedures and STV research works were developed and approved by the authors.

1 Introduction

Single-Track Vehicles (STV) have under mentioned advantages over common automobiles:

- it is easy to operate a Single-Track Vehicles;
- STV have a great mobility in traffic jams;
- STV occupy small parking space, they are really compact while moving;
- STV are not so expensive as traditional automobiles;
- STV have an essential fuel economy.

STV have many advantages but there are also some disadvantages too. This is the reason that prevents STV from being the best among urban vehicles. Some of these disadvantages are actual just for countries located in medium and cold climatic zones.

STV essential disadvantages:

- Single-Track Vehicles don't have a body - this is a reason of the worst passive safety in road accidents; The specific number of deaths per one registered motorcycle is 59 per 100 000. This indicators are more than three times higher than the specific number of deaths occurred in car accidents (17 per 100 000). If we compare the number of deaths of motorcyclists per one kilometer with the number of deaths of automobile drivers and passengers, we will find out that motorcyclists die 22 times more often in road accidents.
- All STV have insufficient stability during driving mode at low speeds and unstable balance while standing still;
- Due to the lack of body the driver and passengers of Single-Track Vehicles may feel unpleasant external influences from snow, rain, wind, dust, etc.

Regarding the safety laws of all Countries it is mandatory to use special devices and clothes for body protection. This may be a hamlet, at least or some kind of a "shell", overall; leggings and so on. But anyway all of these protection items are uncomfortable and awkward. These measures of safeness are obligatory due the open-style construction of STV.

We would like to suggest the best ways of solving of Single-Track Vehicles problems:

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- Clarification of STV moving conception [1];
- Improvement of experimental research methods of brake system's characteristics, controllability and stability during all STV driving modes, including the still position;
- Improvement of STV design and construction;
- Improvement of statutory regulations;
- Training for safety use of STV.

There is a brief description of 5 methods of solving of STV problems. These methods were developed in the course of many years of research in MADI while writing a doctoral dissertation by Gayevsky V.V.

2 Clarification of STV moving conception (first method)

There are two main types of vehicle's moving ways: rectilinear and curvilinear.

Considering the rectilinear moving way we use such features as: acceleration, constant-velocity motion, braking process [2,3,4].

Considering the curvilinear moving way we use such features as: moving with high speed (vehicle's controllability) and moving with a low speed (vehicle's maneuverability).

There are some specific features and variations of STV for each moving style.

Also the balance while standing still is actual for STV.

Peculiarities of rectilinear movement are: low moving speed and one-wheel drive style. Main features of curvilinear movement are: turn availability due to the body careen only; high speed; turning due to steering wheel rotation jerk with reverse center; one-wheel turn way [4,5,6,7].

The equilibrium for a standstill STV is a balancing position on the verge of unstable equilibrium condition. It may be achieved by:

- moving the driver's body (and the passenger's) left-to-right relatively to longitudinal axis;
- moving the steering wheel left-to-right;
- using the flywheel (gyroscopic effect);
- using of additional support device (it may be driver's leg or bearing);
- other types of additional devices for stable position.

The peculiarity of moving with a low speed is a small stabilizing torque from the rotation of the wheels (gyroscopic torque). As the speed is low, the balance is achieved by:

- moving the driver's body (and the passenger's) left-to-right relatively to longitudinal axis;
- moving the steering wheel left-to-right;
- using the flywheel (gyroscopic effect).

One-wheel drive style is a twice unstable balance condition. It is achieved by:

- driver's body shift (balancing);
- verification of force on the wheels (rear wheel - traction and braking, front wheel - braking).

Taking into the consideration all above mentioned information we may determine "STV Critical Driving Modes".

During the "STV Critical Driving Modes" unstable balance is provided by additional driver's force and (or) different auxiliary devices. [8,9,10,11].

Critical driving modes may be divided into two categories (table 1):

Table 1. Critical driving modes.

Rectilinear motion	Curvilinear motion
Balance during standstill position	Sliding turn
Moving with a low speed	Turn due to the body inclination
One-wheel drive style	Turn by using a driven wheel that rotates in the opposite direction from center of turn
	Moving with a low speed
	Turn by using one wheel

To investigate critical driving modes (CDM) of STV it is important to understand when they appear, process and conditions of transformation to normal driving modes. Thus it is necessary to determine parameters and evaluation indicators of CDM.

Evaluation indicators of critical driving modes:

- minimum driving speed during stable rectilinear motion;
- minimum driving speed during stable rectilinear "hands-free" motion style;
- critical speed during the beginning of longitudinal turnover;
- critical value of acceleration (deceleration) during the beginning of longitudinal turnover;
- longitudinal inclination angle during one-wheel style movement;
- work spent for keeping of unstable balance while standstill position;
- maximum speed during the turn action with radius-defined parameters;
- the ultimate transverse careen angle during the turn.

There are specific formulas for rectilinear motion that define critical speed and acceleration (deceleration) during the turnover while moving with a high speed taking into the consideration air-resistance value, overturning moment value and minimum stable speed of STV.

There is a determination of critical speed and recline angles of turning for curvilinear motion during the movement with wide track tires.

There are ways of improvement of STV design based on abovementioned formulas.

The STV movement theory was clarified. Some formulas and coefficients of critical modes of STV movement action and stability related to the theory of operational features were improved as well.

Formulas we've got:

- aerodynamic overturn torque;
- acceleration during overturn beginning considering air resistance force;
- essential engine tractive effort torque for STV rollover action at the start;
- deceleration of rollover start considering the air resistance force;
- overturn torque from driver's quick dash;
- side force on the front wheel that happens from the rear wheel motion during the STV inclination;
- optimal ratio of braking forces considering overturn torque of air resistance force while moving with a high driving speed;
- critical angle of sliding careen depending on the tire width and center of mass height.

It was estimated while the value of the resistance between the wheel and road (dry asphalt) is 0,8 ($\varphi X = 0,8$) then it is high probability for light weight STV (with a high center of mass position) to turn over in case of quick start.

It was determined a rollover condition while moving with a high speed on a flat road during acceleration and braking action.

It was estimated a real careen of STV during driver's shift while STV is turning. It was estimated a theoretical STV careen value (without taking into the consideration a tire width).

For dry asphalt theoretical careen value is 38.66 '. Also STV balance condition was determined.

3 Improvement of methods of experimental research of braking parameters, controllability and steadiness during all STV driving modes (including still condition) [2,4,5]. (second method)

There were developed new methods of experimental research of braking parameters, controllability and steadiness during STV movement:

- "driving with a high speed with different types of driver's position" - this measure allows to determine a rollover torque depending on the value of air resistance force at high speed mode and type of driver's position impact on this torque.
- "hands-free drive mode" allows to estimate minimum stable driving speed of single-track vehicle with such parameters as: gyroscopic wheel torque, restored torque of running-in arm, construction balance of STV itself. Also this measure allows to find out occasional vibrations "wobble effect" while driving with a speed value from 60 to 30 km/h.
- "driving with minimum speed" - this feature allows to determine a minimum stable speed of STV during its straight-line movement and STV driving peculiarities with a low speed;
- "moving in a circle with definite radius value" - this feature allows to determine a critical speed of passing of the circle track and ultimate real careen angle of STV depending on the tire width, height of mass center and driver's actual position.
- "supple curving driving way" allows to determine STV steering parameters and critical speed during curvilinear motion;
- "STV braking procedure using one or two operation control units on the determined track with definite initial driving speed" allows to estimate the efficiency, accuracy and convenience of braking operation of STV [12,13].

4 Improvement of STV design (third method)

Based on recent research results totally new design versions of STV were suggested: with constant vertical wheels position and STV with bodies and additional devices that allows to improve the stability features. New theoretic correlations were developed as well. They define specific features of rectilinear and curvilinear motions of mentioned vehicles. There was performed a comparative evaluation of safety features among traditional automobile and single-track vehicle.

Was estimated that:

- single-track vehicles with constant vertical wheels position and STV with bodies and additional devices that allow to improve the stability features comparing with ordinary STV have stable equilibrium while standing still and moving with a low speed value and higher speed during its turn motion.
- STV air resistance force value is less than the same value of sport car and motorcycle (as the front area section of STV with a body is less than sport car's area and fairness factor is the same as automobile's and less than motorcycle's one).
- the features of transverse stability of STV with a body design and constant vertical wheels position (as the correlation of mass center height (or careen height) to the wheel

width is less than 0,9) are in conformity with requirements of Technical Regulations of Customs Union # 018/2011 "On safety of vehicles".

5 Improvement and completion of statutory regulations (fourth method)

New types of STV are not mentioned in actual statutory regulations (figure 1) at present time. Now there are no statutory regulations and rules for STV at all.

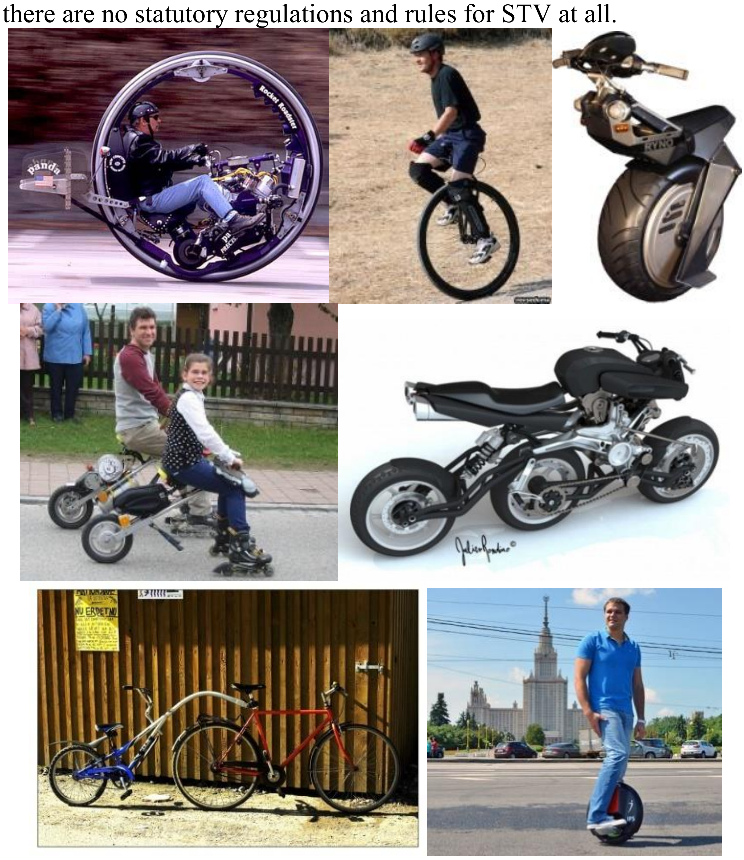

Fig. 1. New types of STV.

There are some types of STV that are subjected to the requirements of basic safety regulations in Russia.

Technical Regulations of Customs Union # 018/2011 "On safety of vehicles". The list of goods that are subjected to the requirements of TR CU 018/2011:

1.1. … Motor bike, motorized bicycle, mokik, including:

- L1 category – Two-wheeled vehicles,
- L2 category - Three-wheeled vehicles with any types of wheels position, with maximum constructive speed not more than 50 km/h
- L3 category – Two-wheeled vehicles, with any types of wheels position, with maximum constructive speed more than 50 km/h
- L4 category – Three-wheeled vehicles with asymmetrical position of wheels regarding to the middle of longitudinal plane

- L5 category – Three-wheeled vehicles with symmetrical position of wheels regarding to the middle of longitudinal plane of the vehicle

Traffic regulations:

- "Bicycle" is a kind of vehicle,...that has at least two wheels ... and may have an electric engine with initial Nmax during a long time session of engine load less than 0,25 kw and automatically switched off while the speed value is more than 25 km/h.
- "Motor bike " is two- or three-wheeled mechanical vehicle with a maximum speed value less than 50 km/h. This vehicle should have an internal combustion engine with a volume less than 50 cm3 or electrical engine with initial designed Nmax (during a long time session of engine load) more than 0,25 kw and less than 4 kw.

6 Guidance of safety use of STV (fifth method)

Much attention should be paid to safety driving of STV. It is very important to make road accidents several times less. It is not a secret any more that more than 80% of all of road accidents relate to motorcycles and other types of STV and happen with the inexperienced drivers with exploitation experience less than 5 years.

At present time Moscow Automobile and Road Construction Institute (State University) has developed several educational programs: "Physical process of bicycles and motorized types of vehicles", "Design features and research methods of STV", "Theory of STV movement". These programs are unique and are used during the educational procedure of master's degree students, technical specialists and bachelor's degree students. [14,15,16]

During these educational programs students may learn such under mentioned study courses:

- STV design features;
- theory of STV movement and horoscope theory;
- recommendations for STV driving ways during critical movement types;
- prevention of STV critical driving modes;
- improvement of STV driving experience.

7 Discussion

Conducted research allowed to create a new type of safe STV and to find criteria for critical driving conditions, which allows in operation to avoid falling into them and improve traffic safety.

8 Conclusions

Solving the complex problems of STV, it is possible to significantly reduce the number of victims in road accidents and increase the safety of STV. The aim of the development of an STV in the world is the creation of a secure STV, comparable in safety to a car.

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