TRIBOLOGY IN BALLROOM DANCE WITH ENERGY CONSUMPTION ANALYSIS

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ABSTRACT

Tribology phenomena are obviously present and have significant importance in most of human activities, processes and actions. Ballroom Dance as a common activitie with practically importance is not enough studied and analyzed from the tribological point of view. This paper presents an attempt in this direction dealing with study of tribology aspects by analyzing a couple of Standard and Latin ballroom dances with characteristic steps and choreography. This paper shows an approximate calculation of friction forces and torques caused by some common movements and their influence on interaction in foot – floor interface. Besides the approximate calculation of friction loss, authors have measured and analyze the total energy consumption by making several experiments with corresponding equipment.

KEYWORDS: tribology, friction loss, foot-floor interface, dance, energy consumption

1. INTRODUCTION

The term "ballroom dancing" is derived from the word *ball*, which in turn originates from the Latin word *ballare* which means "to dance". In times past, ballroom dancing was social dancing for the privileged, leaving folk dancing for the lower classes. These boundaries have since become blurred, and it should be noted even in times long gone, many ballroom dances were really elevated folk dances. Modern ballroom dance has its roots early in the 20th century, when several different things happened more or less at the same time. The first was a movement away from the sequence dances towards dances where the couples moved independently. This had been pre-figured by the waltz, which had already made this transition. The second was a wave of popular music, which led to a burst of newly invented dances. The third event was a concerted effort to transform some of the dance crazes into dances which could be taught to a wider dance public in the Europe and USA */ 1 /*. Nowadays the ballroom dance doubtless takes significant place in human activities, where World Dance Council (WDC) and International Dance Sport Federation (IDSF) classified (Table1) and organize official competitions divided into professional and amateur. Standard/Smooth dances are normally danced to Western music (often from the mid-twentieth century), and couples dance counter-clockwise around a rectangular floor following the line of dance. In competitions, competitors are costumed as would be appropriate for a white tie affair, with full gowns for the ladies and bow tie and tail coats for the men; though in American Smooth it is now conventional for the men to abandon the tail suit in favour of shorter tuxedos, vests, and other creative outfits. Latin/Rhythm dances are commonly danced to contemporary Latin American music, and, with the exception of a few travelling dances (e.g., Samba and Paso Doble), couples do not follow the line of dance but perform their routines more or less in one spot. In competitions, the women are often dressed in short-skirted Latin outfits while the men are outfitted in tight-fitting shirts and pants, the goal being to emphasize the dancers' leg action and body movements.

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International Standard		International Latin	
Waltz	28-30 bars per minute, 3/4 timing	Samba	50-52 bars per minute, 2/4 timing (foot timing 3/4)
Tango	31-33 bars per minute, 4/4 timing	Cha Cha Cha	30-32 bars per minute, 4/4 timing
Viennese	58-60 bars per minute, 3/4 timing	Rumba	25-27 bars per minute, 4/4 timing
Foxtrot	28-30 bars per minute, 4/4 timing	Paso Doble	60-62 bars per minute, 2/4 timing
Quickstep	50-52 bars per minute, 4/4 timing	Jive	42-44 bars per minute, 4/4 timing

Table 1. Ballroom dance classification with music and tempo regulations.

1. SHOE-FLOOR INTERFACE AND COEFFICIENT OF FRICTION

There are many factors that affect slips and falls in shoe-floor interface, but selection of appropriate floor surface type and shoe sole material for the expected use are important design factors under your control that can help in prevention of slips and falls. By analyzing the effects of surface type and composition and by proper selection of floor surfaces for specific conditions, you can reduce the potential for serious accidents.

Coefficient of friction (CoF) is a ratio of sliding force required to move one surface over another to the total vertical force applied to the two surfaces in contact. In simple terms, it is an indicator of “grab” or friction present between the two surfaces in contact. Higher CoF is desirable as it reduces the possibilities of slipping. CoF can be static or dynamic. Static CoF relates to the horizontal force needed for initial movement and dynamic CoF is the force needed to continue that movement in stable walking. Static CoF is generally higher than dynamic. CoF is going to vary considerably for different types of floors, and it is affected by the material (leather, rubber, barefoot) and design of footwear, and also the environmental conditions (wetness, oil, spills and other contaminants). CoF helps in quantifying a floor’s slip resistance and should be used in floor design specifications.

As adopted by Underwriters Laboratory (UL) and the American Society of Testing and Materials (A.S.T.M) a static anti-slip coefficient of friction of 0,50 or above is considered a safe walkway surface with a dry condition. A reading below 0,50 is considered an unsafe walkway surface.” Ceramic, Terrazzo, Marble and most mineral surfaces are actually safer in wet conditions than in a dry untreated surface. All surfaces shall be tested independently for actual results. Table 2 presents recommendations for safety threshold values of CoF in shoe-floor interface, a bit different according to Rosen */ 2 /* and the Wuppertal Safety Standards 1997.

According to Rosen */ 2 /*		Wuppertal Safety Standards 1997	
0,60 or above	→ very safe	0,64 or above	→ very safe
0,50 - 0,59	→ relative safe	0,43 - 0,63	→ safe
0,40 - 0,49	→ dangerous	0,30 - 0,42	→ conditionally safe
0,35 - 0,39	→ very dangerous	0,22 - 0,29	→ unsafe
0,00 - 0,34	→ unusually dangerous	0,00 - 0,21	→ extremely unsafe

Table 2. Slip prevent values of CoF in shoe-floor interface.

For dance floors, e.g., a friction coefficient of 0,5 is definitely too high. For gymnasia, on the other hand, it represents the bottom limit. DIN 18032 Part 2 specifies friction values of 0,5 – 0,7 for gymnasia, measured with a leather glider. For parquet and wood floors, friction values of 0,3 – 0,4 are recommended. According to the Zurich Services Corporation, Illinois (USA) that is dealing with Risk Engineering measurement (CoF) for floor surface is a complex and controversial subject, particularly due to diversity of standards and test methods. American Society of Testing Materials (ASTM) and other organizations have developed several standards.

ASTM D 2047 addresses use of James Machine in laboratory for testing of polish coated resilient floor and floor waxes and coatings. Ceramic and quarry tile industry has adopted ASTM C 1028. Footwear industry uses ASTM F 609 using Horizontal Pull Slipmeter (HPS) for measurement of static slip resistance of material for footwear sole and heels. ASTM F 1679 for use of the English XL variable incident tribometer device for dry and wet testing was withdrawn in 2006. There are a few more test methods and standards in use and adopted by specific stakeholder groups. American National Standards Institute ANSI/ASSE A 1264.1-2007 is the latest of such STF standards that addresses slip resistance of walking and work surfaces in industrial workplaces. In addition to floor and walkway openings, it includes guidance on fixed stairs, platforms and railings. CoF of 0,5 or greater, when measured using the James Machine and leather shoe sensor, has become a commonly accepted minimum threshold for slip resistant surfaces in accordance with Underwriter's Laboratory. A static CoF of 0,6 is accepted for disability accessible walking surfaces and 0,8 for ramps. CoF is not an absolute value for specification. It is not correct or even possible to specify CoF without referring to test method and device used, shoe sensor material and wet/dry test conditions. Many test methods are for laboratory testing and may not be suitable for in situ testing. Consistent CoF measurement using the same method and device can be used for relative comparison of slipperiness between floor surfaces or coatings as part of the selection process.

Above mentioned indicates that coefficient of friction in shoe-floor interface should takes higher values aimed to prevent slip appearance. But in opposite case of too high friction in that interface, higher level of possibly injuries indicated when the foot is planted and firmly fixed to the floor. The purpose of study */ 3 /* was to compare the injury rate between two different floor types: wooden floors (parquet, generally having lower friction) and artificial floors (generally having higher friction). Studies have suggested that there may be a relationship between the shoe–surface interface and injury risk. The wooden floors that were tested (n=13) had a friction coefficient in range 0,36–0,53 compared with 0,46–0,73 for artificial floors (n=60). The main observation of this study was that the risk of injury for women appears to be higher on artificial floors than on wooden floors. Consequently, the injury rate was higher for women than for men on artificial floors, while there was no gender difference on wooden floors.

2. FRICTION LOSS AND ENERGY CONSUMPTION CALCULATION

There are no relevant current investigations directly related to friction phenomena in dancing or similar activities, so here is presented an attempt in such approximately calculation and analysis. Energy loss due to a friction in shoe–floor interface consists of part caused by friction force (during translation) and friction torque (during period of rotation). As a first approximation, power lost by friction in this case we could calculate following the analogue to friction in threaded transmission pair */ 4 /* by expression:

$$P_\mu = P_F + P_T = F_\mu (v + r_\mu \cdot \omega) = m \cdot g \cdot \mu (v + r_\mu \cdot \omega) \,. \tag{1}$$

Where are: m - mass of a dancer (kg); μ - coefficient of friction (CoF) in shoe-floor contact; v – translation dance speed (m/s); r_μ - friction radius of rotation and ω - angular rotational speed (sec^{-1}). Due to a fact that power is energy in time, one can calculate friction energy loss as follows:

$$E_\mu = P_\mu \cdot t = P_F \cdot t_\theta + P_T \cdot t_\rho, \quad (2)$$

$$t = t_\theta + t_\rho. \quad (3)$$

Where are: t – total dance (choreography) duration; t_θ - partial time with translation movement and t_θ - partial time with rotations in choreography.

In aim to make better quality of calculation and results analysis for different kind of dances we can introduce parameters those represent relative influence of rotation (ρ) and translation (θ) in total dance (choreography) duration as:

$$\rho = t_\rho / t = 0 \ldots 1 , \quad (4)$$

$$\rho = t_\rho / t = 0 \ldots 1 , \quad (5)$$

$$\rho + \theta = 1 . \quad (6)$$

Finally we can define the expression for calculation of total energy loss due to a friction:

$$E_\mu = P_\mu \cdot t = P_F \cdot t_\theta + P_T \cdot t_\rho = m \cdot g \cdot \mu \cdot t\,(v + \rho\,(1{,}5\, r_\mu \cdot \omega - v)) . \quad (7)$$

Here should be said that approximately values for dance translation and angular rotational speed are taken based on experience in dance and other sports */5/*, such as values for friction radius of rotation from anthropology literature */6/*. As is shown in expression (7), mean value of total foot area is corrected by factor 1,5 due to a fact of additional area supported on foot out of rotation. It is clear that calculated energy loss due to a friction is just a part of total energy consumption spent in any physical human activity; besides those we have aerodynamic and also energy losses caused by physiology processes. Undoubtedly the total energy loss has quite higher value compared with friction losses; next chapter gives example of its calculation with experimental results analysis.

Heart rate, oxygen consumption and estimated energy during ballroom dancing were studied based on experimental investigations with ten competitive ballroom dance couples (grade amateur or qualified professionals) */7/*. Mean gross energy expenditures indicated that competitive dancing was as demanding as other sporting activities such as basketball (35.83 kJ/min), playing squash (42.70 kJ/min) and cross-country running (44.37 kJ/min). The advanced competitive standard of ballroom dancing thus required all subjects to perform the dance sequences at energy expenditure levels which were classified as heavy to extremely heavy in terms of exercise loading.

There are current on net downloadable programs or tables, such as Energy Expenditure Calculator */8/*, which could be used in approximately calculation of energy consumption for different physical activities, depends on person weight, duration and kind of exercise. It was used in this paper just for verification of calculated friction losses and experimental data for several kinds of ball dances subjected in this study.

3. EXPERIMENTAL INVESTIGATIONS WITH RESULTS ANALYSIS

Since the energy lost to friction obtained computationally, the total energy loss during dance activity we can get by experiments. For this purpose the experimental device CAT EYE (Japan), was used to determine the current and average heart rate, and the total energy consumed during the course of the observed activities. Several experiments were carried out in collaboration with “Dance Club Milonguero”, whose instructors Dragan Pejić and Biljana Koprivica have carried out the selected choreography for the two types from the Standard and

Latin dances (Figure 1). These were the Viennese Waltz, Waltz, Rumba and Cha Cha Cha as typical dances that vary in tempo and manner of performance, where results obtained for 2 minutes choreography are presented in Table 3.

Figure 1: Couple from “Milonguero Dance Club” in rotation starting position for Standard dance.

International Standard			International Latin		
Dance (2 min.)	Mean hart rate (beats/min)	Expenditure Energy (kJ)	Dance (2 min.)	Mean hart rate beats/min	Expenditure Energy (kJ)
Waltz	137	11,76	Rumba	141	12,68
Viennese	166	14,30	Cha Cha	156	13,02

Table 3. Mean hart rate and mean expenditure energy for observed dances.

Obtained experimental results are interesting to analyse in combination with example of friction losses calculated for corresponding dances, taking real experimental conditions into account. This facts were dancer (man) mass of 96kg, coefficient of friction value of 0,52 for leather shoe sole-oak parquet interface, radius of friction during rotations 31,8 mm, recommended values for translation velocity 1m/sec and rotational speed of 1 turn/sec, due to a rhythm and timing rate of dances. Results of friction losses calculation based on above mentioned conditions are performed for different contribution of rotations in dance choreography and could be presented graphically at the Figure2. Environmental conditions for experiments were standard temperature in range of 18-22 ^{0}C and relative humidity around 60%.

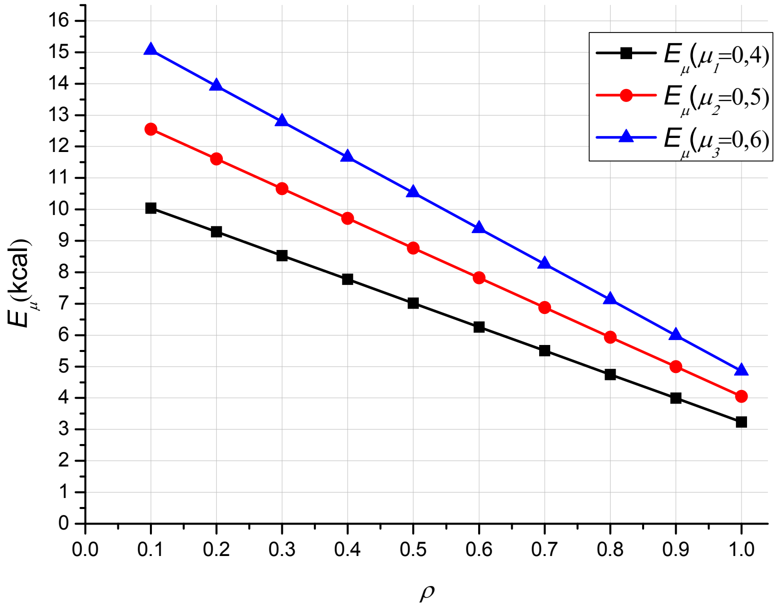

Figure 2: Friction losses in dance for different CoF (μ) depending on rotation factor.

Descending trend of friction energy loss (E_μ) with rising rotation factor (ρ), implicates that most of energy occurs due to translation and only a part belongs to energy lost during the turns in a dance. The influence of foot-floor interface materials selection is also shown, where coefficient of friction should be in range 0,4 to 0,6. These values for coefficient of friction implicate leather as a common material for shoe sole and for proper dancing floor usually is selected oak parquet, wood or marble. This choice is also up to particular dance or activity, where this analysis could be useful. Focused on particular dances, those have different rotation factor, contribution of friction loss in total expenditure energy could be analysed as on Figure 3. The Viennese Waltz undoubtedly has the longest history of all ballroom dances because its precursors originate back to the 12th century. Already in case of the Round – the dominating dance in the Middle Ages – the final turn of the dancing couple was the highlight. This complete turn is characteristic of the Viennese Waltz. The rhythm is first of all interpreted by the turns. It is marked by rises and falls. The music flows fluently and swings lively. It is danced at 60 beats per minute. As it requires the most stamina, the Viennese Waltz is half a minute shorter than the other standard dances. Due to a fact of dominant rotations in Viennese, the rotation factor of around 0,7 is taken for this paper analysis purpose. This is made according to several typical Viennese choreographies observations, but it could be a bit modified in case of more experiments in further investigations. Compare with the Viennese, other dances have less influence of rotation, where analysis for selected observed dances such as Waltz, Cha Cha and Rumba is shown in following diagram. Results of calculation for different dances show that particular dances with more rotation influence indicate small reaction in foot-floor interface, compared with dominant translation dances where friction losses in this interface are higher.
By comparing results from calculations and energy consumption values obtained by experiments, one could conclude that even more rotation affect less foot-floor friction loss, such a kind of dance is physical harder due to a higher tempo and requires much more total energy.

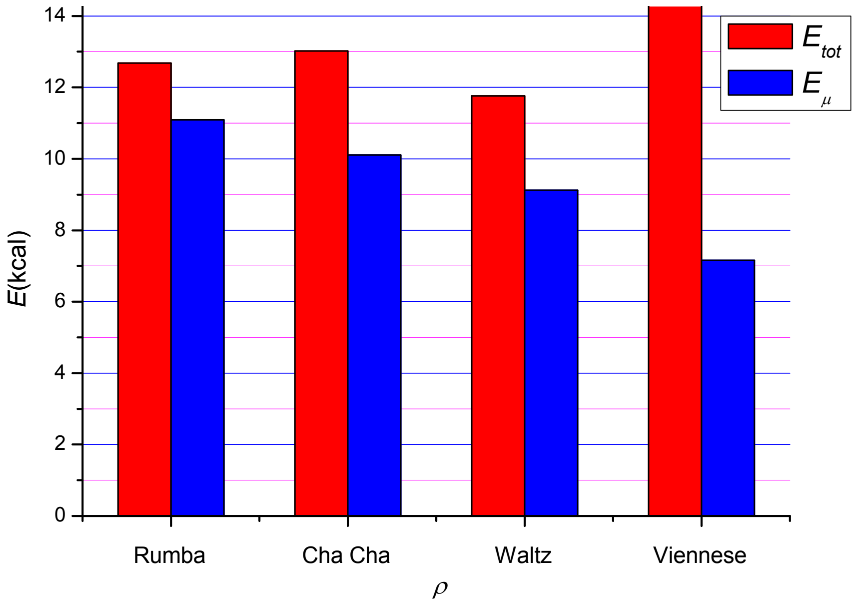

Figure 3. Total energy consumption and friction losses for particular dances.

4. CONCLUSIONS

Tribology characteristics of shoe-floor interface are very important due to a significant influence of friction losses in total energy consumption during ballroom dance as a human activity. Proper choice of shoe sole such as floor material use to be conducted for particular dance, which means that coefficient of friction should be enough to prevent slip dangerous, but not too high in aim to avoid potential injuries. Material choice could vary for different physical activity, where for both Standard and Latin dances, proper combination could be leather shoe sole on oak parquet. Of course that floor condition, cleanliness such as loading conditions and sliding speed affects coefficient of friction values, but it was not a point of this paper and used to be widely explored.

Calculated friction losses in foot-floor interface and experimental results could give us some interesting conclusions concerning the ballroom dance. It seams that more rotations in particular choreography produce less friction losses in foot-floor interface, but from another hand it requires higher total energy consumption due to a higher energy losses absorbed by the joints and muscles. Typical dance of this type is the Viennese, with the proportion of highly expressed rotations (≥70%) which is very attractive, but physically more demanding than other Latin dances such are Rumba and Cha-Cha.

Energy expenditures indicate that competitive dancing was physically quite hart, as demanding as some other sporting activities such as basketball, squash or country running.
This attempt in study of friction phenomena in dance is only a step in possible investigations, where also influence of different foot-floor interfaces, choreography such as gender or couple skill level impact on particular dances could be further investigated.

This paper and similar investigations could be interesting for some floors and shoes products manufacturers subjected to make an optimal product for preferred activity (as dance), aimed to reduce energy consumption from one side but also to prevent possible undesirable from another side.

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