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SIOMMS: Evolution and development

1. Introduction

Following its mission of promotion of Machine and Mechanism Science (MMS) among young people all over the world, the Executive Council of IFToMM in Guanajuato, Mexico, June 2009, has resumed establishing the regular Student International Olympiad on MMS (SIOMMS) [1,2]. Such events meet greatly one of the main challenges for IFToMM of the attraction and interest of the young generation and national communities to IFToMM and its activity [3,4]. Up to the moment, there is a good history of such events (see Table 1). On October 24–26, 2018, the recent competition was held at Pontifical Catholic University of Peru, Lima, Peru.

2. Insight into Olympiad topics

The primary objectives of conducting SIOMMS are to motivate young people to make study and research in the field of Mechanics, Machine Design and Analysis; to reveal most talented students; and provide them with a facility for competition. The more broad and fundamental effect of the events in the aspect of society is on not less importance. During the study and preparation period as well as during the event, including the competition itself plus lectures and master-classes delivered by leading professors and researchers, the participants can acquire qualities required for a qualified mechanical engineer, such as the qualities of an analyst, researcher, designer, computing engineer, effective communicator, team-worker, open-minded person, and even more [5,6]. The teachers involved in the process of training the participants of the competition are given the opportunity to improve their skills. They study national and foreign MMS courses and solve research problems with the most talented students. In many technical universities, there is a significant reduction in MMS academic hours. So, the role and importance of preparing and participating in such events are difficult to overestimate.

As a rule, the problem sets include knowledge on seven main MMS topics. The topics and how they were presented in the contest problems are shown in Table 2 for the first four Olympiads (+ means that the topic was included).

The details of the topics are given in Table 3 for every Olympiad.

At the first two Olympiads, the regulation provided for a written solution of eight problems within four hours without a break. At the Olympiads in Spain and Peru, the number of tasks and the procedure for solving them were changed: five tasks were proposed for solving within two sessions of 2.5 hours each. There was an hour break between sessions.

In developing International Olympiads, there is an increase in the quality of participants’ preparation. Table 4 shows the results of the winner of each Olympiad as a percentage of the maximum possible number of points. Obviously, the success of the participants is affected by the complexity of the competition problems. In addition, the participants’ age increases, the SIOMMS Regulations allow for the participation of both undergraduate and graduate students. Therefore, students get the opportunity to participate in such competitions several times; for example, some participants of SIOMMS2018 have already participated in SIOMMS 2016. Great experience and many years of training have a positive effect on the results. It would probably be fair (but challenging to put into practice) to differentiate the level of difficulty for participants in various categories.

Preparation and participation in the Olympiads are extremely positively considered by the participants - students. Below are just some examples of feedback received from Russian students participated in competitions in different years.

To achieve a result in the competition, discipline, accuracy, attentiveness, non-standard thinking, optimization of work is necessary. These qualities were developed in the MMS classes.

Students get opportunities to develop and realize themselves as professionals in the engineering field. A fundamental knowledge helps in the further development of the career of successful engineers and managers.

During the preparation for the Olympics, students learned a lot, grew up mentally, gained knowledge that gave potential and opportunities in their future career.

https://doi.org/10.1016/j.mechmachtheory.2020.104029
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Today many former participants work as designers, engineers, and researchers. Some of them develop unique robotic complexes and automated lines. And they use the knowledge gained in the classroom on the theory of mechanisms and machines almost every day.

Classes were held in a friendly, close-knit atmosphere. Step by step, students realized that they were becoming part of the MMS and IFToMM community.

These reflections, published by students on social networks, confirm the outstanding cultural and educational significance of MMS competitions for future engineers [5].

3. Examples of contest problems

As an example of contest problems, the texts of the tasks offered at the SIOMMS 2011 in Izhevsk, Russia are given below.

Problem 1. In the mechanism shown (see Fig. 1), crank 1 rotates clockwise with an angular speed of 60 rpm and imparts a horizontal reciprocating motion to the rack 4 through the slider 2 and the rocker 3. The rocker carries the toothed sector at its end. The rocker's section BD is curved and has the shape of a circular arc.

All necessary linear and angular dimensions can be read on the scheme drawn to scale $K_l = 0.002$ m/mm.

**Determine:**

1. Velocity and acceleration of the rack 4 when angle $O_2O_1A$ is $90^\circ$.
2. Time ratio of the rack 4.
3. The length of stroke of the rack 4.

Problem 2. In the cam mechanism with a knave edge reciprocating follower, the cam 1 rotates with a constant angular velocity $\omega_1$, see Fig. 2. The follower is kept in contact with the cam by a spring (not shown). The part AD of the cam's profile is an involute of the circle with radius OC, the part AB is straight, and BAC & ACO are right angles.

**Questions:**

1. Prove that in the position shown the change of acceleration $\Delta a_{A_2}$ of the follower due to the change of the cam profile curvature is given by $\omega_1^2 \Omega \sec^4 \theta$.
2. If the mass of the follower 2 is $m$, write down the expression for inertia force.

Problem 3. In the four-bar linkage shown in Fig. 3 crank OA of length $l_{OA} = 0.30$ m rotates with angular speed of $\omega_1 = 10$ rad/s. Crank AB has length $l_{AB} = 0.80$ m, mass $m_2 = 10$ kg, and moment of inertia $I_{S2} = 0.40$ kg m$^2$ about center of mass $S_2$.

The location of the center of mass $S_2$ on the link AB (i.e., $l_{AS2}$) is not specified.

Determine kinetic energy $E$ of the connecting rod AB in a position such that angle $\phi_2$ takes extreme (maximum or minimum) value. Determine also how the expression for the kinetic energy $E$ depends on sizes $l_{AB}$ and $l_{AS2}$. 

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Table 1
SIOMMS in progress.

| Title            | Date, year       | University, country                                      | Number of teams | Participating countries                                                                 |
|------------------|------------------|----------------------------------------------------------|-----------------|----------------------------------------------------------------------------------------|
| SIOMMS 2011      | April 19–21, 2011| Kalashnikov Izhevsk State Technical University (ISTU), Russia | 17              | China, Czech Republic, Egypt, Hungary, Russian Federation, Slovakia, Syria, Ukraine     |
| SIOMMS 2013      | October 12–13, 2013| Shanghai Jiao Tong University, Shanghai, China            | 15              | China, Japan, Malaysia, Russia, South Korea, Spain                                      |
| SIOMMS 2016      | October 20–21, 2016| University Carlos III of Madrid, Spain                    | 15              | China, Germany, Japan, Peru, Russian Federation, Spain, USA                            |
| SIOMMS 2018      | October 24–26, 2018| Pontifical Catholica University of Peru, Lima, Peru        | 13              | China, Germany, Peru, Russian Federation, Spain, USA                                    |

Table 2
Problem topics.

| Topic                                                                 | SIOMMS 2011 | SIOMMS 2013 | SIOMMS 2016 | SIOMMS 2018 |
|-----------------------------------------------------------------------|-------------|-------------|-------------|-------------|
| Structural analysis and dimensional synthesis of linkages             | +           | +           | +           | +           |
| Kinematics of plane mechanisms                                        | +           | +           | +           | +           |
| Cam                                                                    | +           | +           | –           | +           |
| Geometry of toothed gearing                                           | +           | +           | +           | –           |
| Gear trains                                                            | +           | +           | +           | +           |
| Balancing                                                             | +           | +           | –           | +           |
| Mechanism dynamics, differential equation of motion, fluctuation of energy, equivalent mechanism | +           | +           | +           | +           |
### Table 3
Detailed topics.

| Title          | No | Topic and content                                                                                                                                 |
|----------------|----|---------------------------------------------------------------------------------------------------------------------------------------------------|
| SIOMMS 2011    | 1  | Kinematic analysis of the 5-bar linkage with a curvilinear coulisse (method of velocity and acceleration diagrams), investigation of a time ratio. |
|                | 2  | Kinematic analysis of a cam mechanism (geometrical method).                                                                                       |
|                | 3  | The kinetic energy of the linkage link in a given particular position.                                                                            |
|                | 4  | Engagement of involute spur gear wheels (velocity of the slip of one tooth relative to the mating tooth at the phases of the beginning and end of engagement). |
|                | 5  | Kinematical synthesis of the gearbox (selection of missing numbers of teeth, with the overall gear ratio given), finding the mechanism’s actual DOF (mobility). |
|                | 6  | Dynamics of the coulisse mechanism (setting up the differential equation of motion, balancing the coulisse’s force of inertia).                   |
| SIOMMS 2013    | 1  | Structural analysis of the linkage, including identification of local degrees of freedom, redundant constraints, and dismembering the mechanism into Assur kinematic chains. |
|                | 2  | Kinematics of a plane four-bar coulisse mechanism (graphical and analytical solutions).                                                           |
|                | 3  | For one pair of external involute spur gears determining shift coefficient provided the minimum center distance and no undercut.                    |
|                | 4  | Kinematic synthesis of the slide-crank four-bar linkage based on three given positions by both graphical and analytical methods.                  |
|                | 5  | Static balancing of a five-bar planar manipulator situated in a vertical plane.                                                                      |
|                | 6  | Kinematic investigation of a multi-link gear mechanism containing a planetary gear train and worm gear.                                             |
|                | 7  | For a given cam mechanism with a flat-face follower: pressure angle in a given position, diagram of the follower’s displacement, finding an analytical expression for distance from the contact point between the follower and the cam to the centerline of the follower, an analytical expression for the cam profile. |
|                | 8  | Reduction of forces and masses in the given mechanism, finding for the equivalent link $\omega_{\text{max}}$, $\omega_{\text{min}}$ according to a given coefficient of fluctuation of angular speed, finding average power of the motor. |
| SIOMMS 2016    | 1  | Analytical synthesis of an off-center crank-slide mechanism using the Freudenstein’s equation. For a steady-state operation of the machine unit, the determination of the average speed of rotation and the coefficient of speed fluctuation on the base of the Wittenbauer diagram. The number of teeth and gear ratio in the epicyclic gearbox. |
|                | 2  | Kinematic analysis of a coplanar six-bar mechanism (geometric method, velocity & acceleration diagrams).                                            |
| SIOMMS 2018    | 5  | For the involute gearing of three spur wheels calculation of working pressure angle, radial clearance, and contact ratio. Cases of wheels manufactured without and with the displacement of the cutting rack are both considered. Kinematic analysis of a coplanar six-bar coulisse mechanism (instant centers of velocity; graphical solution for acceleration on the base of Goodman’s analysis for kinematic inversion). Application of virtual displacement principle for finding input moment. |
|                | 4  | Synthesis of four-bar linkage of the function generation type by kinematic inversion and Chebychev spacing.                                        |
|                | 5  | Balancing of a four-mass system rotating in a single plane. Turning moment diagram for a four-stroke engine, fluctuation of speed. Finding $\omega_{\text{max}}$, $\omega_{\text{min}}$, constant moment of resistance, and moment of inertia of a flywheel. Compound gear train: determining tooth numbers. Epicyclic gear train: finding the transmission ratio. |

### Table 4
Best results obtained (in percent of maximum points).

| Olympiad | SIOMMS 2011 | SIOMMS 2013 | SIOMMS 2016 | SIOMMS 2018 |
|----------|-------------|-------------|-------------|-------------|
| Results  | 47          | 78          | 90          | 90          |

**Problem 4.** Two 20 involute spur gears have a module of $m = 5$ mm. Gear 1 has 20 teeth, and gear 2 has 40, a standard rack cuts both without shift. The gears have the coefficient of radial clearance is $c^* = 0.25$; the addendum is equal to the module $h_a = m$.

**Questions:**

1. What conditions are to be satisfied for the gear ratio of two spur gears to keep constant during the whole period of teeth engagement?
2. Determine the sliding velocity $V_{312}$ of wheel 1 with respect to wheel 2 at the positions of entering and leaving the engagement. Consider the wheel 1 as a driving one, rotating making $n_1 = 2000$ rpm.

**Problem 5.** A gearbox used to drive the drum in a hoisting mechanism (see Fig. 4) has been destroyed because of overloading. Because the drawings of gears were lost, the only information below is available about the gearbox:

- all gear pairs have identical modules;
Fig. 1. Scheme of the mechanism of Problem 1.

Fig. 2. Cam-follower mechanism of Problem 2.
Fig. 3. Four-bar linkage of Problem 3.

Fig. 4. The gearbox of Problem 3.

√ gears 4, 5, 7 have $z_4 = 63$, $z_5 = 24$, $z_7 = 72$ teeth, respectively;
√ gears 1 and 3 have an equal number of teeth, $z_1 = z_3$;
√ all gears are cut with a standard tool (angle of pressure 20°, the addendum is equal to the module $h_a = m$; the radial clearance $c^* = 0.25$ coefficient is no shift).

Questions:

1. Calculate mobility of the gearbox. Reveal idle degrees of freedom, if any.
2. Determine the number of teeth for all unknown gears provided the gear ratio of the mechanism is to be 22.

Problem 6. In the mower cutting mechanism shown in Fig. 5, the crank $O_1A$, rigidly attached to the gear wheel 1 imparts motion to the rocker 3 (the mower knife) through the slider 2. Gear wheels 1 and 4 have the number of teeth $z_1$ and $z_4$, correspondingly.

It is known:

√ $l_{OA}$, length of the crank;
√ links 2 and 3 have masses $m_2$ and $m_3$, respectively, these are concentrated at the centers of mass A (link 2) and B (link 3);
√ the moment of inertia of wheel 1 keyed with the crank equals that of wheel 4, $I_{O_1}^{(1)} = I_{O_4}^{(4)}$ (both are known); the moments of inertia are calculated about centroidal axes of rotation;
√ constant working load $F$ acts on the rocker 3;
√ driving torque $M_D$ is applied to the wheel 1.
Fig. 5. The mechanism of Problem 6.

Fig. 6. The mechanism of Problem 8.
Questions:
1. Obtain the differential equation of the mechanism motion.
2. Counterbalance the inertia force acting on the rocker 3 through attaching two identical counterweights of mass \( m \) to the wheels 1 and 4. Determine the masses of counterweights and angular positions they must have on the wheels. Both masses should be at a distance \( r \) apart the axes of the wheels. The crank rotates at a constant angular speed of \( \omega_1 \).

Problem 7. A machine press is driven by an electric motor, delivering power \( P = 2.2 \) kW continuously. At the beginning of the working operation, a flywheel with a moment of inertia \( I = 50.5 \) kg\( \cdot \)m\(^2\) has a rotational velocity of 250 rpm. The pressing process requires \( 4750 \) J of energy and takes time of 0.75 s.

Find the maximum number of pressings that can be made during 1 hour and the reduction in speed of the flywheel after each pressing. Neglect friction losses.

Problem 8. In the cam mechanism shown in Fig. 6, the follower 2 has the mass of \( m_2 = 0.1 \) kg. On the rise of the follower, its displacement is given by the equation \( s = 0.5S_{\text{max}}(1 - \cos\frac{2\pi}{360}q) \), where \( q \) and \( q_0 \) are the angles of cam 1 corresponding to a variable position and the extreme upper position, respectively.

Questions:
1. What is the angular position \( q^* \) of the cam when the driving moment \( M_D \) takes the maximum value?
2. Find \( M_{D,\text{max}} \) with the following data: the cam rotates at a constant speed \( \dot{q} = 100 \) rad/s, the length of the follower stroke (lift) is \( S_{\text{max}} = 30 \) mm, the end of the rising phase corresponds to the cam angle of \( q_0 = 120^\circ \).

Participants relatively easily solved Problems 5 and 7. At the same time, it happened that the topics of the kinematics of coulisse mechanism (Problem 1), toothed gearing (Problem 4), and dynamics of the cam mechanism (Problem 8) suggested a sort of challenge for students. Participants did only a few complete and correct solutions. Typical misunderstandings and errors are highlighted in [7].

Conclusion

International Olympiads present a significant challenge for both participants and their tutors. One of the aspects is the difference in the specific subject content of institutional MMS study courses. MMS as a science contains a large number of topics, many of which are very specific. It is relatively difficult to master all of them equally well in conditions of limited study time. Teaching MMS in national traditions can emphasize different aspects. Therefore, for organizing successful Olympiads, it is essential to conduct a comparative content analysis of MMS courses and develop general recommendations for both authors of contest problems, and participants. It should be done soon.

In preparing for the Olympiads, we recommend using textbooks and research papers (some examples can be found in [8–14]), which offer both geometric and analytical methods for solving problems, as well as examples of computer modeling. Compendiums of Olympiad problems [15], which summarize the contest experience, will also be useful. Since SIOMMS are held in English, it will be helpful to use multilingual dictionaries and thesauri for TMM in the training period [16–20]. It is advisable to provide an opportunity for students - potential participants taking a professional English course.

To keep young people interested in MMS and involved in the mechanism and machine science community there is also a need to bridge the gap between textbook knowledge and recent researches both in well-established areas and within hot topics are expected to get great importance and influence in the coming years. Here the journal of Mechanism and Machine Theory plays a very important role as one of the key international instruments for technical exchange in the field of mechanism and machine science [21]. The journal publishes also articles highlighting SIOMMS issues representing common interest for MMS educators.

An essential part of the program of any SIOMMS is the holding of lectures and presentations for participants on innovative technologies in MMS. Below there are two examples of lectures held in the course of SIOMMS 2018 (Lima, Peru).

Professor Juan Antonio Carretero (University of New Brunswick, Canada), a member of the Executive Board of IFFToMM, presented a report on the topic “Appropriate design and analysis of mechanisms.” The report noted that the uncertainties that are an integral element of the production and management of mechanisms are usually ignored in the analysis and synthesis of mechanisms since they are difficult to introduce into the calculation. However, the effectiveness of real mechanisms depends on the uncertainty, so there is a need for reliable methods that could reveal the mechanisms’ correct parameters. Appropriate design methods based on interval analysis are developed, in particular, for the analysis and synthesis of parallel mechanisms, for example, the parallel mechanism of the 3-RRR structure. The tasks are solved to determine the manipulator’s working area with the identification of singularities and other features that can guarantee the fulfillment of the required duty by the mechanism. The synthesis methods under discussion can explore the space of design parameters to determine the full set of design options for the mechanism that will ensure the fulfillment of the objective function. More information is available in [22,23].

Professor Andres Kecshkemethy (University of Duisburg-Essen, Germany) devoted his presentation to numerous robotics applications for the analysis and modeling of the movement of the human body. Since 2019, Professor Kecshkemethy is the IFFToMM President.
Thus, in addition to providing opportunities for competition, SIOMMS, as noted above, facilitate the exchange of information in the academic environment, motivate students, and make a cultural and educational influence on them.

The next, fifth Student International Olympiads on MMS – SIOMMS 2020, by the decision of the IFToMM Executive Council, was to be held in October 2020 at the Kalashnikov Izhevsk State Technical University M.T. Kalashnikov (Izhevsk, Russia). But due to the global emerging COVID-19 issues, travel restrictions, and safety concerns, it was postponed. The new dates are 19–21 May 2021 in Izhevsk, Russia, so in fact, it will be SIOMMS20/21.

The reinvigoration of the Student MMS Olympiads and incorporating them in the process of solving innovation challenges for mechanism design is considered now as one of the priorities of IFToMM activity [3,4,24]. The main challenges for SIOMMS are, in our opinion, focused on the following aspects.

- The attraction of students from different countries on the base of the stronger activity of IFToMM member organizations.
- Better visibility of the information relevant SIOMMS and presented in the FToMM website & documents of planned IFToMM activity.
- Coordination between IFToMM PC for Education and other PCs and TCs for both attraction of student teams and renovation of contest topics.
- Publishing collections of contest problems, papers, and articles about MMS Olympiads.
- Possible new future formats of competition in the context of COVID-19. The online format has many pros and not fewer minuses. Among others, a plagiarism issue is one of the most difficult for solution. The discussion about new formats could be launched by PC for Education within the IFToMM community.
- Support for participating teams by making SIOMMSs the events in the social and political life of the IFToMM community, national regions, and countries.

Declaration of Competing Interest

None.

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Revised 15 July 2020