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Comprehensive Hazard Analysis and Risk Management Strategies in Forging Operations: A Systematic Evaluation of Workplace Safety and Operational Risks

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Abstract

Forging industries are critical suppliers to automotive, aerospace, construction, and manufacturing sectors, operating in high-risk environments with heavy machinery, extreme temperatures, and hazardous materials. This study employs a comprehensive Hazard Identification and Risk Assessment (HIRA) methodology to systematically evaluate risks in forging operations. The research identifies and categorizes multiple risk domains, including mechanical, thermal, chemical, and ergonomic hazards. By applying rigorous assessment techniques, the study quantifies risks based on severity, probability, and exposure levels. It proposes a multilayered risk mitigation strategy encompassing engineering controls, administrative interventions, and enhanced personal protective equipment (PPE). The findings emphasize the importance of proactive safety management, providing a structured framework for continuous risk monitoring and effective workplace hazard minimization in forging environments.

1. Introduction

Manufacturing processes have long been the backbone of industrial development, with forging standing out as a critical metalworking technique that enables the production of high-strength components across multiple sectors. Forging machines play an integral role in metalworking, transforming raw materials through high-energy operations involving extreme temperatures and complex machinery. However, this essential manufacturing process is simultaneously characterized by significant occupational hazards that pose substantial risks to worker safety. The implementation of the Job Safety Hazard Identification and Risk Assessment (JSHIRA) methodology in Industry 4.0 settings demonstrates a significant breakthrough in workplace safety, successfully eliminating over 50% of potential workplace hazards through a systematic, comprehensive approach that integrates technological automation with proactive risk management strategies [1]. The proposed goal-oriented risk analysis approach integrates stakeholder interests with system requirements, extending the Tropos framework through a three-layered conceptual model (assets, events, and treatments) to systematically identify and mitigate risks during the early requirements analysis phase [2].

2. Occupational Hazards and Safety Imperatives in Metal Forging: A Comprehensive Risk Analysis Framework

2.1. Occupational Risks in Forging Industries

The forging industry presents a unique and challenging work environment marked by inherently high-risk operations. Occupational injury statistics underscore the critical nature of workplace safety in these settings. According to the Occupational Safety and Health Administration (OSHA), metal forging workers experience an injury rate of 5.2 per 100 full-time workers, significantly higher than many other industrial sectors. The injury landscape in forging is diverse and severe:

- Crushing injuries from presses and hammers account for a substantial portion of workplace accidents
- Approximately 30% of injuries involve hand and finger trauma, with some resulting in partial or complete amputations
- Thermal burns constitute nearly 20% of reported injuries, primarily due to hot metal handling
- Eye injuries from flying metal particles and sparks represent 15–20% of workplace incidents
- Repetitive stress and physical strain contribute to 10% of reported injuries, including back problems and sprains

The gravity of these risks is further emphasized by fatal injury statistics from the U.S. Bureau of Labor Statistics, which report a fatal injury rate of 3.0 per 100,000 workers in metal forging. These incidents often result from crush injuries in automated presses or severe burns from furnace-related accidents. [4]

2.2. Research Motivation and Significance

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3. Research Methodology: Hazard Identification and Risk Assessment (Hira) in Forging Processes

3.1. Preliminary Planning and Preparation

The systematic risk management approach follows a comprehensive, structured methodology that begins with meticulous classification of work activities. This initial phase provides a foundational understanding of the operational landscape, enabling precise hazard identification. Once work activities are thoroughly classified, a detailed hazard identification process is undertaken, systematically mapping potential risks associated with each operational segment. Following hazard identification, a rigorous risk determination process evaluates the severity, probability, and potential impact of each identified hazard. The critical next phase involves developing control measures using a hierarchical approach that prioritizes elimination and substitution of risks before implementing engineering controls, administrative interventions, and personal protective equipment (PPE). A comprehensive risk control action plan is then meticulously prepared, detailing specific mitigation strategies, responsible personnel, implementation timelines, and resource requirements. The final stage involves a comprehensive review and validation of the action plan, ensuring its adequacy, practicability, and potential effectiveness in mitigating identified workplace risks. This iterative process ensures continuous improvement in safety management, creating a dynamic framework that adapts to changing workplace conditions and emerging potential hazards.

3.2. Scope Definition

The forging industry represents a complex manufacturing environment characterized by multiple high-risk stages, from initial billet cutting to final shot blasting. Each process stage—billet cutting, heating, hot forging, piercing, trimming, and shot blasting—presents unique safety challenges requiring comprehensive risk management strategies. The workplace safety approach demands a meticulous understanding of mechanical, thermal, and ergonomic hazards inherent in metal transformation processes.

3.3. Initial Documentation Review

Collection of existing safety documentation The comprehensive safety documentation collection for Hazard Identification and Risk Assessment (HIRA) in forging processes represents a critical foundation for systematic risk management. This multifaceted approach encompasses gathering documentation from diverse sources, including internal incident reports, regulatory compliance documents, technical equipment specifications, material safety data sheets, and worker-related records. The collection methodology integrates systematic document inventory techniques, ensuring thorough and confidential compilation of safety-related information. By synthesizing data from operational logs, regulatory guidelines, equipment manuals, and historical safety records, the process creates a robust knowledge base that enables detailed risk analysis, identifies potential hazards, and supports the development of proactive safety interventions. The documentation collection serves as a strategic framework for understanding workplace risks, facilitating continuous improvement in safety protocols, and ensuring compliance with evolving industry and governmental safety standards. [5]

3.4. Review of Material Safety Data Sheets (MSDS)

The Material Safety Data Sheet (MSDS) for the graphite forging lubricant reveals a nuanced profile of chemical safety characteristics and handling requirements. While the lubricant demonstrates non-flammable and non-hazardous properties, it presents specific potential health risks that necessitate careful workplace management. The MSDS highlights potential hazards including eye irritation and skin sensitization, underscoring the critical importance of appropriate personal protective equipment (PPE). Specifically, workers are mandated to utilize protective gloves, safety goggles, and respiratory masks when handling the chemical to mitigate direct exposure risks. The documentation also warns about potential slip hazards from spilled product, emphasizing the need for immediate cleanup protocols and careful material handling procedures. This comprehensive safety assessment provides essential guidance for safe storage, handling, and emergency response strategies, ensuring workplace safety and regulatory compliance in industrial environments.

3.5. Analysis of Previous Incident Reports

The systematic analysis of previous incident reports in forging processes represents a critical diagnostic tool for comprehensive workplace safety management. By meticulously examining historical accident documentation, the investigation reveals intricate patterns of workplace risks, categorizing incidents across mechanical, thermal, chemical, and ergonomic domains. The analytical approach transcends traditional reporting, transforming raw incident data into strategic insights that uncover root causes, identify systemic vulnerabilities, and predict potential future risks. Through quantitative and qualitative assessment techniques, the analysis provides a nuanced understanding of incident frequencies, severity distributions, and underlying organizational factors contributing to workplace accidents. This data-driven methodology enables proactive risk mitigation, supporting the development of targeted safety interventions, refined operational protocols, and continuous improvement strategies that fundamentally enhance workplace safety in high-risk manufacturing environments.

3.6. Examination of Legal and Regulatory Compliance Requirements

Table 1 explain to the legal compliance framework for forging processes represents a multifaceted approach to managing workplace safety, environmental protection, and operational risk mitigation ions.

Table 1 **Legal and Regulatory Compliance Requirements**

S. no.	Machine	Legal section	Descriptions	Compliance requirements
1	Hoist Crane	Section 28	Hoists & Lifts	Inspection to be done every six months once
		Section 29	Lifting Machines & Tackles	Every 12 months for general safety compliance
2	Billet Cutting machine	Sections 21-26	Safety of Machinery & Equipment	1. Fixed or interlock guard to be provided. 2. Emergency stop to be provided.
		Section 35	Eye Protection	Workers must wear Safety goggles or face shields to protect from metal chips and sparks
		Schedule XXVIII	Operation involving	Hearing protection (earplugs or earmuffs) for

			high noise levels	workers
		Section 41C	Hazardous Processes	Medical checkups for workers exposed to high noise
		Section 14	Removal of Dust & Fumes	Dust collection system required
3	Forging machine	Sections 21-26	Safety of Machinery & Equipment	Safety guards for moving parts, Regular inspection and maintenance of forging machines, Emergency Stop Mechanisms
		Section 35	Eye Protection	Protective goggles or face shields
		Schedule XXVIII	Operation involving high noise levels	Hearing protection (earplugs or earmuffs) for workers
		Section 41C	Hazardous Processes	Regular medical checkups
4	Shot blasting machine	Section 14	Dust & Fumes	Adequate dust extraction systems required
		Section 13	Ventilation & Temperature	adequate air circulation required to prevent heat stress
		Section 41c	Hazardous Processes	Regular health check-ups must be conducted for workers

4. Hazard Identification Methodology

4.1. Identification Techniques

The outcomes of workplace walkthrough surveys and structured interviews with employees using in-hoist cranes are given below.

4.2. Using Hoist Crane

4.2.1. Hazards Involved

- Slipping over the bars while putting the hanger belt for lifting
- Falling of bars while moving the bars bundle near to the cutting machine by using hoist crane
- Hoist rope cutting and material falling down.
- Hoist over travel and getting accident.
- Hoist failure due to overloading, wear and tear or poor maintenance
- Brake failure leading to uncontrolled load movement resulting in accident
- Gear and motor malfunction resulting in sudden stops or uncontrolled movement
- Poor communication between the operators
- Improper use of controls can lead unintended movements.
- Improper lifting techniques when manually handling slings or chains

4.2.2. Current Control Available and Further Control Required

- Procedure for lifting and load limits.
- Ensuring operators and riggers are trained.
- Eye test for the operator as per Tamil Nadu factories rules
- Periodic testing of hoist yearly once by Competent person
- ropes and slings periodic testing every 6 months once.
- Display of SWL.
- Periodic maintenance of Hoist
- Trained operators
- Slinging procedure and methods to be developed and trained
- Check sheet for checking the hoist condition on daily basis
- Gobo projector can be fixed in the hoist crane to alert the by passers
- Separate walk way and the lifted load movement.
- Load to lifted must be ascertained for weight before lifting. tag mentioning the bar bundle weights to be tied to the bars.
- Sign boards must be kept in the ways while crane movement to limit trespassers causing the way.

4.3. Billet Cutting Machine

4.3.1. Hazards involved

- Falling of bars while loading into the billet cutting machine
- Contact with the sharp edges in the bars while inserting in the machine stand
- Contact with the high-speed sharp blades while machine running
- Contact with the sharp blades while changing the blades
- Exposure to noise while cutting operation
- Exposure to coolant mist from the machine
- Moving parts trapping fingers, hands or clothing
- Sparks may be ejected during cutting.

- Fire initiation because of absence of coolant while cutting.
- Contact with hot surface and billets can cause burns
- Flying metal fragments due to improper cutting or tool failure
- Blades can shatter and cause injury

4.3.2. Current Control Available and Further Control Required

- Trained operators for crane operation and slinging
- PPE usage cut resistance gloves, earplug and goggles [6]
- Guards for covering the rotating parts.
- Front door to cover the cutting location.
- Ensuring Combustible free work place near the cutting machine.
- Regular maintenance of Billet cutting machines
- Ensure Persons working near to the cutting machine has to wear goggles.
- Mist/dust collector to be installed to collect the dust and dirt’s
- Machine front guards to be interlocked to avoid opening the door and inserting hands when cutting work is in operation.
- Daily safety check sheet to be prepared for the billet cutting machine and ensured safety.

4.3.3. Billet Heating

Hazards involved

- Falling of billet basket while loading, leading to bodily injury.
- Heated billets can get contact with operator body cause severe burn injury
- Continuous exposure to high temperature can cause stress and heatstroke
- Risk of shock due to insulation failure or wire damage [7]
- Grounding fault can cause electrical discharge
- Induced currents in the nearby metallic objects may pose risk of burn or shocks
- Risk of hand or finger caught or pinched in moving parts of the conveyors or rollers.
- Heavy billets dropping can cause crush injuries in legs and hands
- Miss alignment can cause jamming, equipment damage or ejection of billets
- Exposure to smokes from the induction heat
- Noise exposure from the high frequency induction systems.
- Hot metals near flammable materials lead to ignition of fire.
- Cooling system failure for the induction heating lead to fire.
- Exposure to hot billet while moving the hot billet to forging.
- Chances of motor overheating, panel fan getting dust and panel terminals and equipment overheat.
- Loose terminals of power connection.
- Short circuits in the panel due to electronic failure. [8]

4.4. Current Control Available and Further Control Required

- Usage of PPE (heat resistance gloves, face shields, safety goggles, mask, ear plugs and shoe)
- Machine guards and Guards for the rotating and movement parts.
- Regular preventive maintenance of machine and cooling system.
- Ensuring combustible free work area.
- Mancoolers for operators
- Double earthing for the machines and panels to avoid ground faults electronic components of panels to avoid short-circuit.
- Current control available
- Earth pit resistance monitoring on yearly basis
- Training for operators.
- Ensuring dust collectors for dust collection
- Conduct regular inspection of dies.
- Emergency stop to stop the machine in case of malfunction.
- Ensuring hydraulic and pneumatic free of leaks
- Lifting the die by hooking the slings in eye bolt.
- Leak free LPG cylinder hose
- Cylinder kept under chained condition.
- Heat resistance hose for the wires near the heaters to avoid insulation failure
- Cover for the fans placed for operators to avoid unknowingly turning the fans by the operator and getting injured by getting contact with fan blade.

- GCFI or RCCB for tripping of power in case of electronic component failure and short-circuit.
- Thermography check of motors, power terminal connections and leading to fire in panel.
- Providing electrolyte drinks to replenish the lost energy lost through sweat during summer.
- Sign boards displaying “Hot objects “in the work place.
- Barricading for the Hot forged component pallets
- Flash back arrester for the LPG torch to prevent fire. [9]
- Daily safety check sheet to be prepared for the billet heating machine and ensure safety.

4.5. Piercing and Trimming of Forged Parts

Hazards involved

- Risk of crush fingers by caught in the presses, shears, trimming
- Risk of pinching in dies and conveyors
- Ejection of small metal pieces or broken parts fly off during piercing or trimming.
- Risk of Sharp edges on trimmed parts.
- Sparks from the hot metal’s particles can ignite combustibles nearby.
- Faulty wiring or controls can lead to electrical shocks.
- Risk of high noise level
- Exposure to metal dust or fumes
- Risk of metal dust accumulation can lead to fire hazards
- Risk of ignition of combustibles due to hot metals
- Chances of motor overheating, panel fan getting dust and panel terminals and equipment overheat.
- Loose terminals of power connection. [10]

4.6. Current Control Available and Further Control Required

- Usage of PPE (heat resistance gloves, face shields, safety goggles, mask, ear plugs and shoe)
- Machine guards and Guards for the rotating and movement parts.
- Regular preventive maintenance of machine and cooling system.
- Ensuring combustible free work area.
- Man coolers for operators
- Double earthing for the machines and panels to avoid ground faults
- Earth pit resistance monitoring on yearly basis
- Training for operators.
- Ensuring dust collectors for dust collection
- Heat resistance hose for the wires near the Piercing operation to avoid wire insulation failure.
- GCFI or RCCB for tripping of power in case of electronic component failure and short-circuit.
- Thermography check of motors, power terminal connections and electronic components of panels. [11]
- Daily safety check sheet to be prepared for the billet heating machine and ensure safety

4.7. Shot Blasting of Forged Component

Hazards involved

- Risk of high velocity particles can cause eye and skin injuries.
- Moving parts like conveyor, turbines can cause caught/pinch injuries.
- Worn out nozzles, hoses can cause accidents
- Risk of caught accidents in belt and chain drives.
- Exposure to fine dust from the blasting media
- Exposure to high noise level
- Risk of slippery floors due to spillage of abrasives.
- Spark from the metal blasting can ignite flammable materials.
- Clogged filters can overheat and lead to fire

4.8. Current control available and Further Control Required

- Usage of PPE (heat resistance gloves, face shields, safety goggles, mask, ear plugs and shoe)
- Machine guards and Guards for the rotating and movement parts.
- Regular preventive maintenance of machine and cooling system.
- Inspecting seals and gaskets regularly in blast chambers.
- Ensuring nozzles are in good condition
- Ensuring dust collectors for dust collection

- Regular cleaning of filters in the dust collectors
- Installation of rubber curtains at the loading and unloading area.

4.9. Hazard Classification and Tool

Types of Hazards are:

- Mechanical Hazards
- Thermal Hazards
- Chemical Hazards
- Ergonomic Hazards
- Electrical Hazards

Failure Mode and Effects Analysis (FMEA) represents a sophisticated, systematic approach to hazard identification that transcends traditional risk assessment methodologies. By meticulously examining potential failure modes, their underlying causes, and comprehensive consequences, FMEA provides a structured framework for proactively identifying and mitigating risks in complex industrial environments. The methodology's strength lies in its ability to systematically map potential vulnerabilities, quantify risk through detailed analysis of severity, occurrence, and detection parameters, and generate actionable insights that enable organizations to develop targeted intervention strategies. Through its rigorous, data-driven approach, FMEA transforms hazard identification from a reactive process to a strategic, predictive risk management tool, particularly critical in high-risk environments such as forging processes. [12]

5. Risk Assessment Framework

5.1. Risk Evaluation Criteria

The comprehensive risk assessment matrix presents a sophisticated framework for evaluating workplace hazards across multiple dimensions, methodically categorizing risks from minimal to critical levels. By systematically analysing factors including noise exposure, temperature conditions, physical injuries, burn potential, illness risks, and ergonomic challenges, the framework provides a nuanced approach to understanding workplace safety. The matrix progresses from Rating 1 (lowest risk), characterized by minimal impacts and rare occurrences with highly effective control measures, to Rating 5 (highest risk), which encompasses critical conditions involving potential hospitalization, permanent disability, and continuous hazardous exposures. Each risk rating meticulously documents potential consequences, from momentary discomfort to severe health implications, enabling organizations to develop targeted, proactive safety interventions. This multi-dimensional assessment tool transforms complex workplace risk data into a structured, actionable format, supporting informed decision-making, precise risk mitigation strategies, and comprehensive workplace safety management across industrial environments. (Figure 1)

Rating	SEVERITY OF RISKS						PROBABILITY OF OCCURRENCE	PRESENT CONTROL	
	NOISE	Temperature in °C	INJURY: PHYSICAL INJURY	INJURY: BURN INJURY	ILLNESS	ERGONOMICS			
1	up to-65 dB(A)	Room temp 28– 32˚C	Injury such as small cuts	Superficial burns with immediate recovery and person can return back to work immediately	Momentary discomfort / Nuisance Eg. Head ache, Burning of eyes, Giddiness, person can return back to work immediately after rest,Skin irritation	Stress / Strain	More than six months / rare occurrence	Control available and effective	**1**
2	66 to 75 dB(A)	Room Temp - 33-35 ˚C	Injury requiring self attention / First Aid causing suspension of activity for more than 1 hour to 4 Hour	Superficial burns with recovery within half day and person can return back to work	Prolonged discomfort Eg. Diarrhea, vomiting, Constipation , eye strain	Effect on vision / Mild ache	More than a Month to Six Month	Control available and not effective	**2**
3	61 to 75 dB(A)	Room Temp - 36-38 ˚C	Injury requiring self attention causing suspension of activity for a day	Superficial burns with recovery within 1 - 2 day and person can return back to work	Minor health impact / requiring nurse/ Self attention Eg. Viral Fever, fever due to water contamination etc.	Upper limb disorder / repetitive strain injury (RSI)/Back Ache	More than a week to one month		
4	76 to 90 dB(A)	Temp at work place between 39 – 43˚C	Minor accident causing Injury requiring self / nurse/ doctor's attention leading to suspension of activity for more than a day or two	First degree burns with recovery above 2 days and person can return back to work	Major Health impact requiring doctor's attention returning back to work after 2 days or more	Blood pressure / Heart disease / Nervous breakdown/ Sprain	More than a day to 1 week	Control not available	**3**
5	≥ 90 dB(A)	Temp at work place beyond 44˚C	Major Accident / Hospitalization / requiring a week to month to return back to work / fatality .	Second degree burns with recovery more than 1 month to return back to work	Permanent disability / residual impact eg. Respiratory illness	Residual occupational ergonomic risk	Multiples times a day or continuous		

Figure 1 **Risk Evaluation Criteria**

Fundamental Calculation

RPN = S x P x PC

where,

S = Severity

P = Probability of Occurrence

PC = Present Control

The Risk Priority Number (RPN) methodology represents a sophisticated approach to systematic risk management, integrating three critical dimensions of risk evaluation: severity, probability of occurrence, and existing control effectiveness. By meticulously quantifying potential workplace hazards, this analytical framework transforms complex risk landscapes into actionable insights, enabling organizations to move beyond subjective risk perceptions. The methodology's strength lies in its ability to comprehensively assess risks by considering the potential impact of an incident, the statistical likelihood of its occurrence, and the current mitigation strategies in place. Through this multi-dimensional analysis, safety managers can prioritize interventions, allocate resources strategically, and develop targeted risk reduction strategies. The RPN calculation serves as a powerful diagnostic tool, providing a standardized, objective mechanism for identifying high-impact risk areas, supporting continuous safety improvement, and fostering a proactive approach to workplace risk management that transcends traditional reactive safety protocols.

Example Calculation [13]

If a risk has: Severity = 5, Probability = 3, Present Control = 2 then RPN = 5 × 3 × 2 = 30

5.2. Criteria for significance

These are the conditions decided for arriving at the significant hazards and associated risks. The following are the criteria decided for taking care of the stringency of the system defining the significance levels.

- All emergencies - not rated.
- Legal non compliance
- Classification of risk – Un acceptable risk rating (RPN >=24)
- Severity level - 4 and above
- Present control = 3
- (Any control either Engineering or Administrative control is not available will be considered as significant) [14]

6. Risk Control Methodology

It is a technique that utilizes findings from risk assessments, which involve identifying potential risk factors in a company's operations, such as technical and non-technical aspects of the business, financial policies and other issues that may affect the well-being of the firm. Table 3 discussed about the risk Control Methodology. [15]

Table 3 Risk Control Methodology

Elimination	The job is redesigned so as to remove the hazard. Elimination is a permanent solution and will be attempted in the first instance. Ex. Elimination of process
Substitution	To replace source of high hazard with a lesser one. Ex: Replacement of material
Engineering control	Involve some structural change to the work environment or work process to place a barrier to or isolation of the hazardous process or interrupt the transmission path between, the worker and hazard. This may include isolation or enclosure of hazard, machine guards and manual handling devices etc.
Administrative controls	Reduce or eliminate exposure to a hazard by adherence to procedures or instructions / signage board. Eg. OPC, MSDS, Safety Training Programs,Standard Operating Procedures (SOPs), Regular Safety Inspections, Safety Communication Protocols, Emergency Response Planning.
Personal Protective equipment	Personal protective equipment will be considered as a last measure when all the above-mentioned controls are not feasible due to technological options, financial, operational and business requirements and the views of interested parties etc. If chosen, PPE will be selected and procured & distributed to the persons who use it. Workers will be trained in the function and limitation of each item of PPE. PPE may be used as a temporary control measure until other alternatives are installed.

Results and Conclusion

Lot of hazards were identified during the risk assessment process and the control measures are determined to reduce the consequences may occur due the hazards Identified in the workplace. From all the hazards identified from the work place, Risk of hands, fingers or limbs crushed if caught in the die press in the forging press and piercing and trimming operation is found to be most critical one as the injury can lead to amputation and in severe case can lead to fatality to the workers. The study on hazard identification in the forging industry highlights significant risks associated with high-temperature operations, heavy machinery, and manual material handling. Key hazards include exposure to extreme heat, fire and mechanical hazards from presses and inhalation of harmful fumes or dust. Effective mitigation measures involve implementing proper personal protective equipment (PPE), regular equipment maintenance, engineering controls such as ventilation and automation, and comprehensive worker training programs. A proactive safety culture, supported by risk assessments and compliance with safety regulations, is essential in reducing workplace accidents and ensuring a safe forging environment.

Future Work

The assessment process is completed with the help of the safety personnel, production personnel, maintenance personnel and with information support from the workers, with help of Safety personnel and maintenance department in the plant the control measures will be implemented to eliminate the hazard or reduce the severity or probability of occurrence of the risk and implementing effective control. The next review of the risk assessment will do after a six month or if there is any change or modification in the machine or in the shop floor or any inadvertent event like near miss or accident. Hence the Assessment to be reviewed and conducted upon new installment or change in work progress.

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